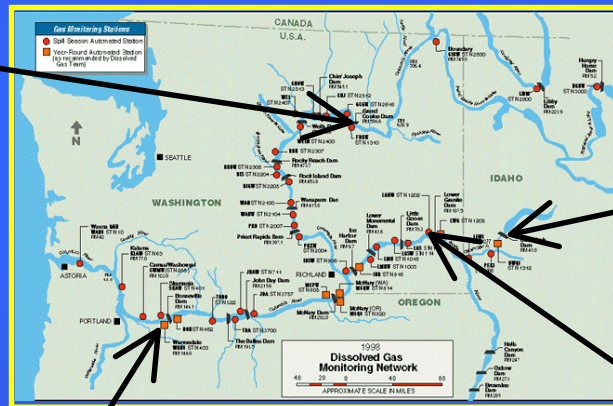


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

US Army Corps of Engineers  
Portland Oregon, July 12, 2000



Grand Coulee Dam



Dworshak Dam



Bonneville Dam



Lower Granite Dam

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

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- **Introduction** - Total Dissolved Gas Abatement Called for by the NMFS Biological Opinion
  - TDG Exchange Research and Development
    - Dissolved Gas Abatement Study & Fasttrack Program
    - Joint Study at Chief Joseph and Grand Coulee Dam for Abatement of TDG
    - PUD's FERC Relicensing
  - Evaluation of TDG Abatement Alternatives
    - Laboratory - Scaled Physical Models
    - Field Studies
    - Numerical Model

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- Purpose

- Major Finding from TDG Exchange Research Programs
  - Spill Management
  - TDG Abatement
- TDG Management Tools that have been developed as a result of these Programs
  - TDG System Spreadsheet Model

# Total Dissolved Gas Exchange

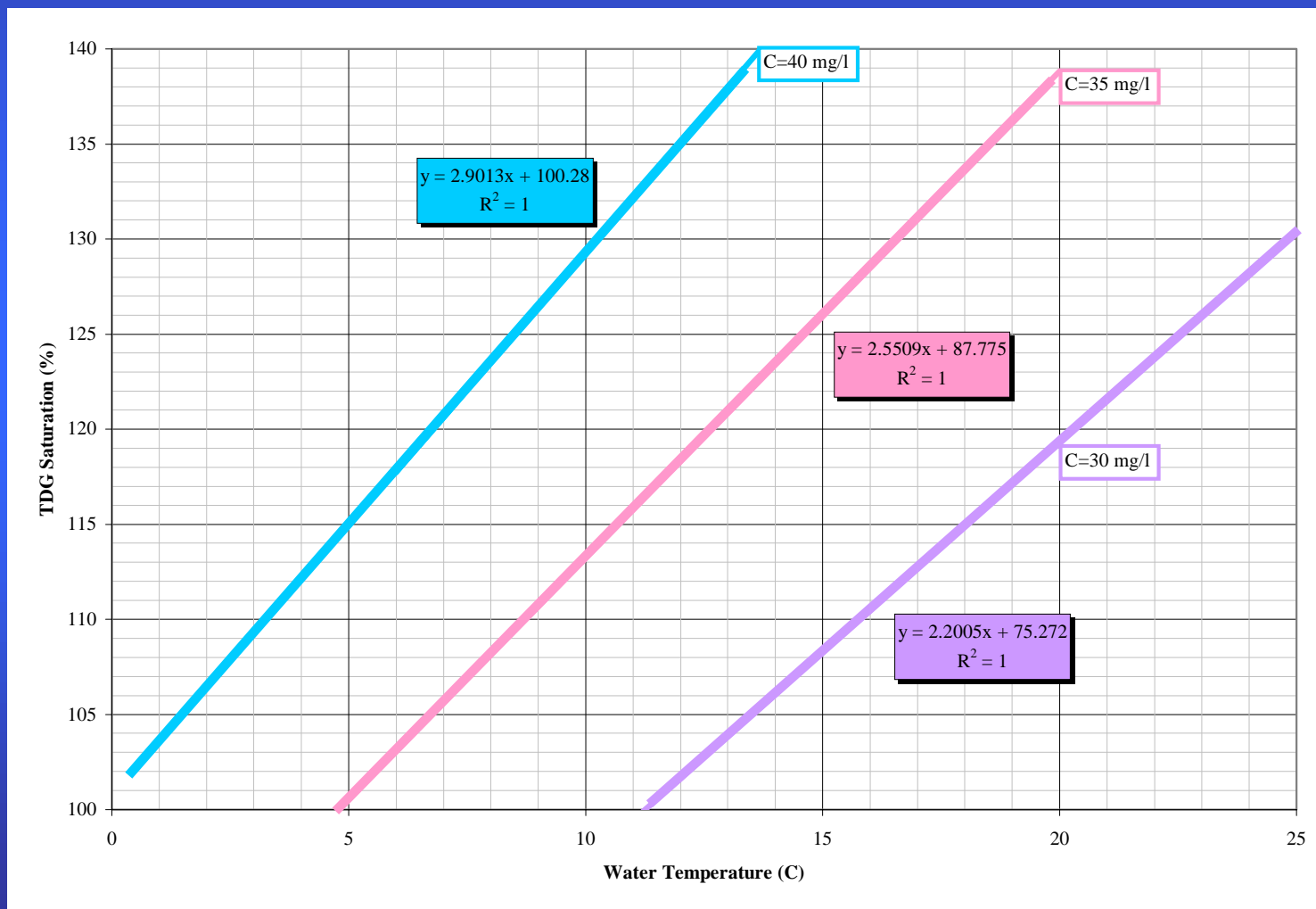
## Dissolved Gas Properties in Water

---

- Gas Solubility
  - Pressure
    - Barometric Pressure
    - Elevation
    - Water Depth (10m ~ doubling of solubility)
      - Compensation Depth  $C_s = C$
      - Air entrainment
  - Temperature  $C_s$  inversely proportional to T
    - Atmospheric Heat Exchange
    - Tributary Inflow

# Total Dissolved Gas Exchange

## Dissolved Gas Concentrations in Water



# Total Dissolved Gas Exchange in Aerated Flow

---

- Air/Water Interface
  - Entrained bubbles
  - Water surface – stream reaeration
- Pressure time history of bubbles
  - Higher pressures accelerate gas transfer
  - Depth of plunge of highly aerated flow
- Turbulence
  - Water surface renewal
  - Retention of entrained bubbles

# Total Dissolved Gas Exchange

## Near-Field Processes

---

- Spillway
  - Approach to Spillway Gate
  - Spillway
  - Stilling Basin
  - Tailwater Channel
- Powerhouse
  - Turbine Passage does not change the TDG properties
    - Exception when air is introduced during rough settings
  - Entrainment into Aerated Spillway Flow

# Total Dissolved Gas Exchange

## Near-Field Processes

---

- TDG Exchange Functional Relationships
  - Spillway Discharge
    - Unit Discharge  $q_s$  (kcfs/bay)
      - Spill Pattern
  - Tailwater Elevation
    - Stilling Basin and Tailwater Channel Depth
    - Deflector Submergence
      - Aerated Jet Development
      - Entrainment Demand

# Total Dissolved Gas Exchange

## Near-Field Processes

---

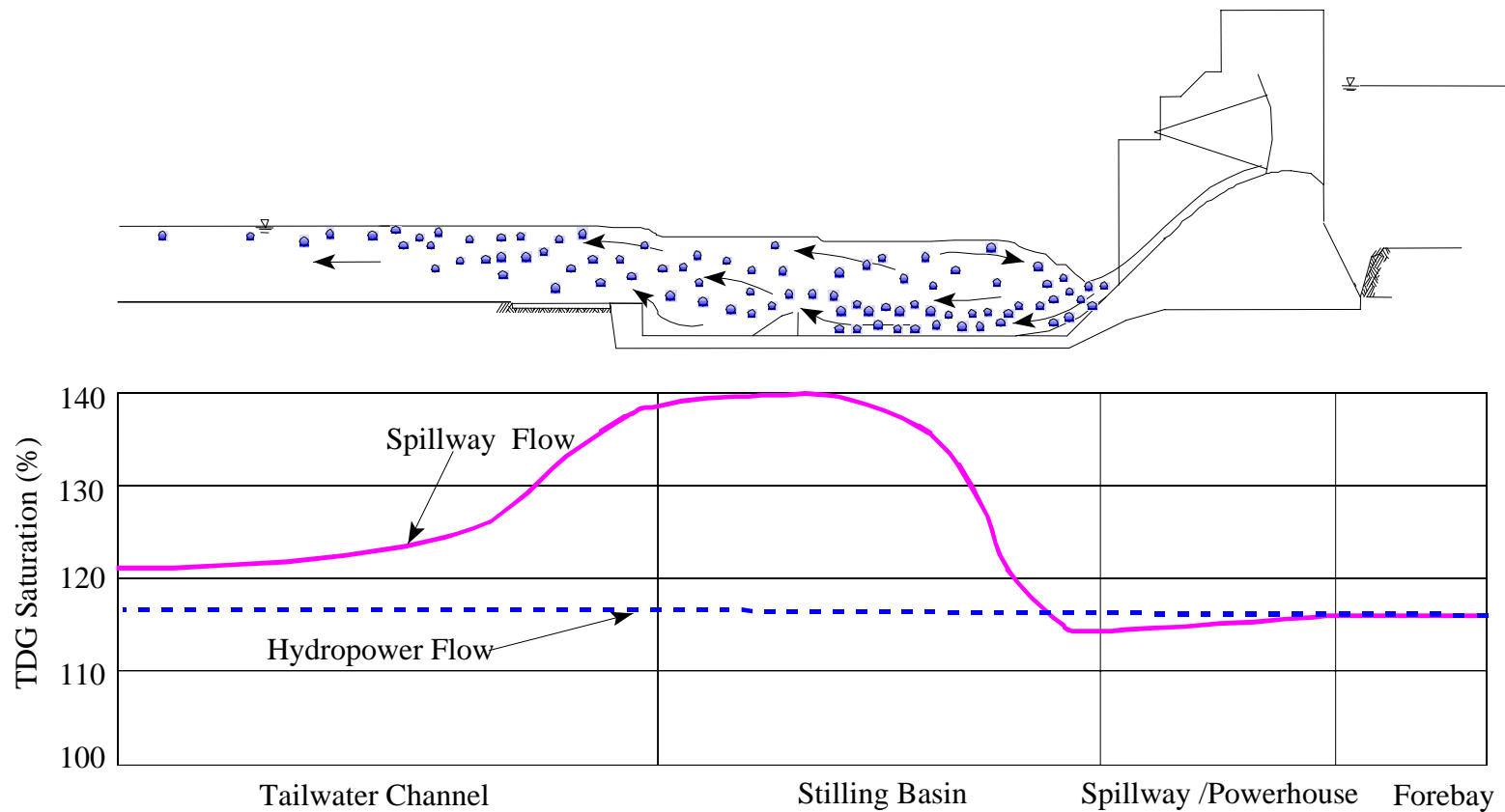
- TDG Exchange Functional Relationships
  - Structural Configuration
    - Spillway Gate
      - Notched and Split Leaf
      - Sluiceways
    - Spillway Design
      - Flow Deflectors
      - Training Walls and Piers
    - Stilling Basin
      - Endsill and Baffle Blocks
      - Depth and Length
    - Orientation of Powerhouse

# Total Dissolved Gas Exchange Near-Field Processes

---

- TDG Exchange Functional Relationships
  - Bathymetry
    - Tailwater Channel
  - Total Project Head
  - Water Temperature
  - Initial TDG Pressure

# Total Dissolved Gas Exchange Near-Field Processes

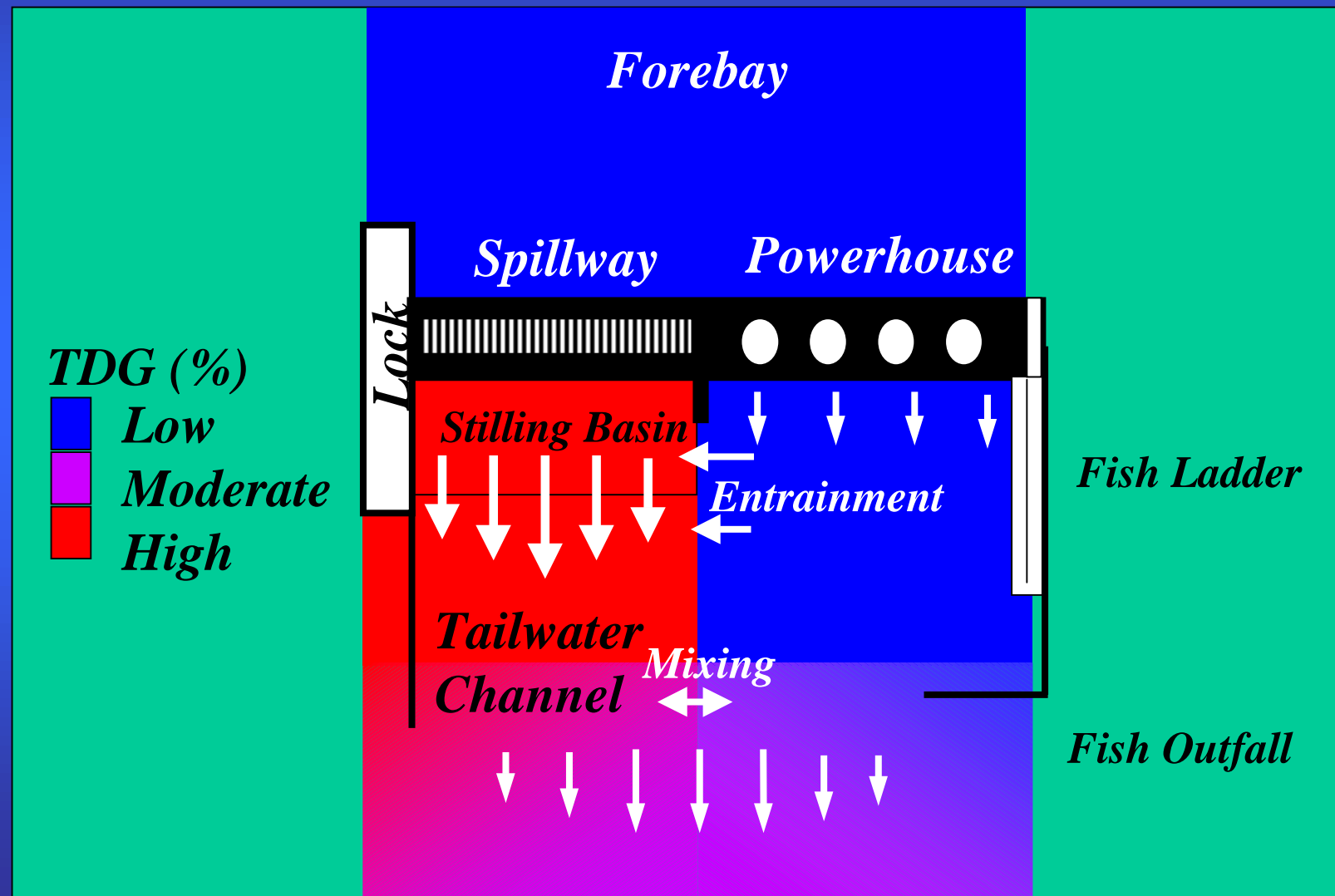


# Total Dissolved Gas Exchange and Mixing: In-Pool Processes

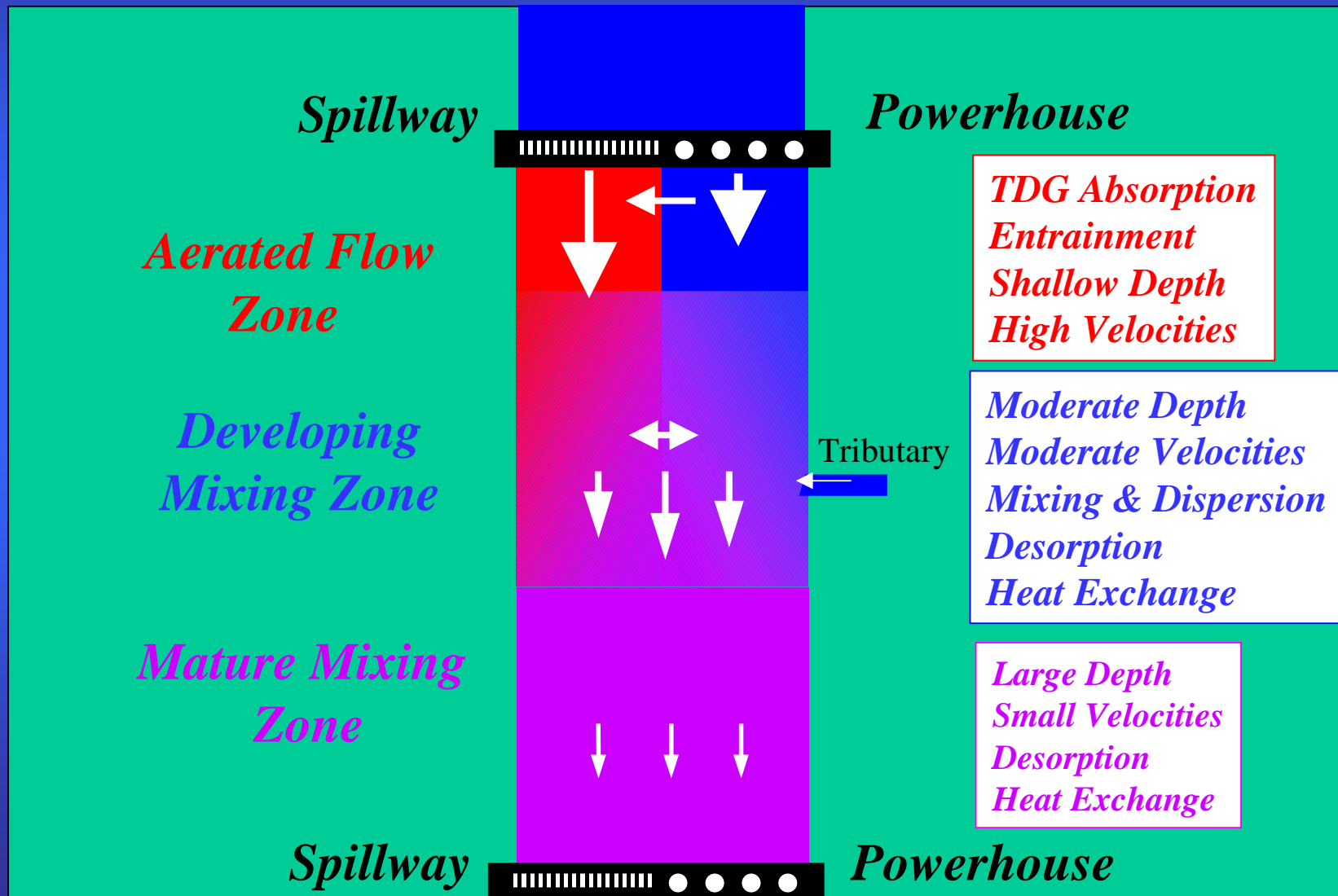
---

- Transport and Mixing
  - Attenuation of TDG Fronts
    - Redistribution of TDG Concentration
  - Tributary Inflow
- Water Surface TDG Exchange
  - Wind Induced
- Thermal Heating and Cooling
  - Warming increases TDG Saturation

# Total Dissolved Gas Exchange at Dams in the Columbia River Basin

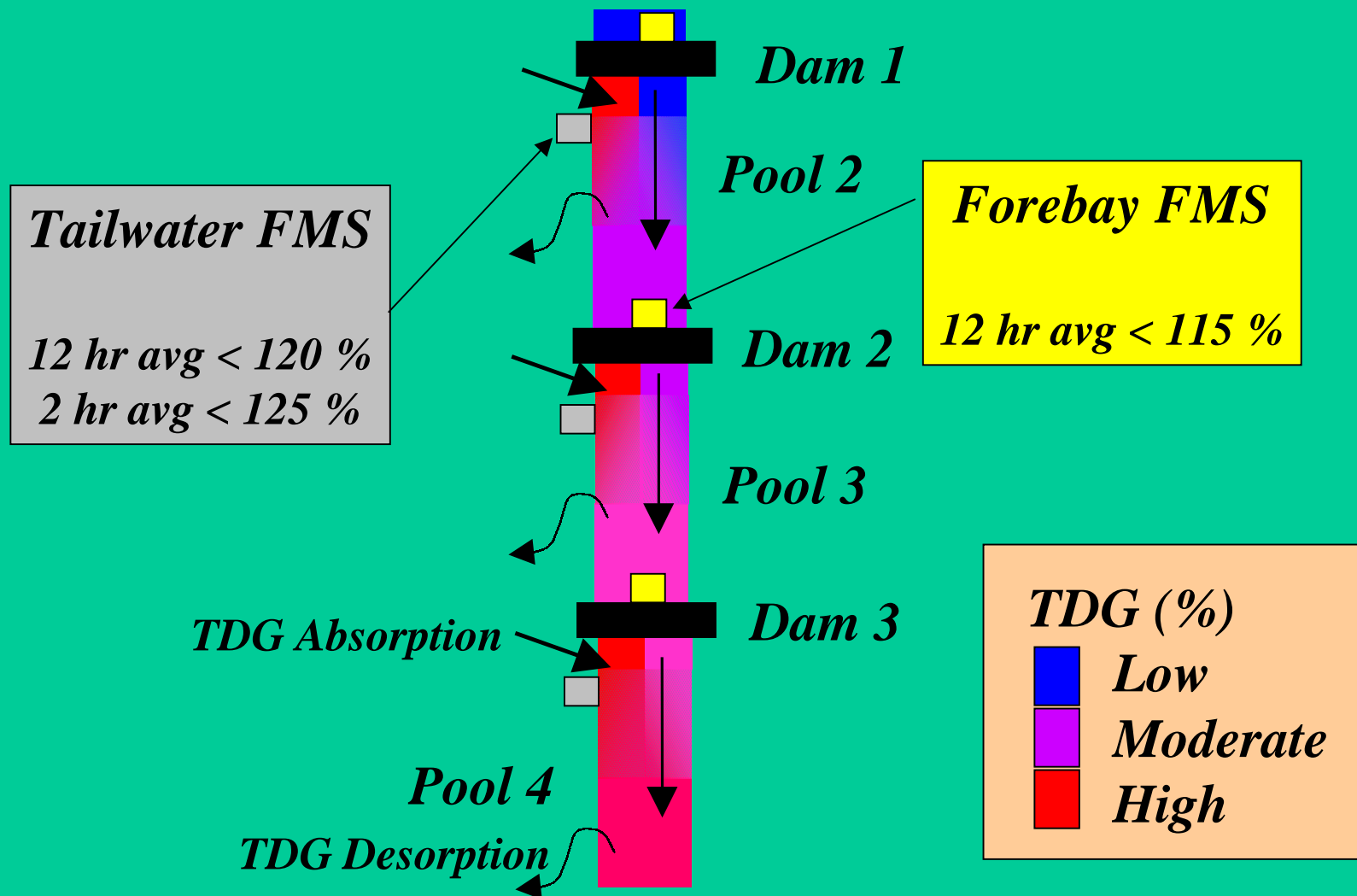


# Total Dissolved Gas Exchange at Dams in the Columbia River Basin



# Total Dissolved Gas Exchange

## TDG System Properties and Spill Management



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

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## – System Characteristics

- Dams
  - Spillway
  - Powerhouse
- River Reach
  - Length, Width, Depth

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

## – System Characteristics (continued)

- Operation
  - Spillway
    - » spill pattern
  - Powerhouse
- Water Quality
  - Temperature
  - Total Dissolved Gas

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

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## – Fixed Monitoring System

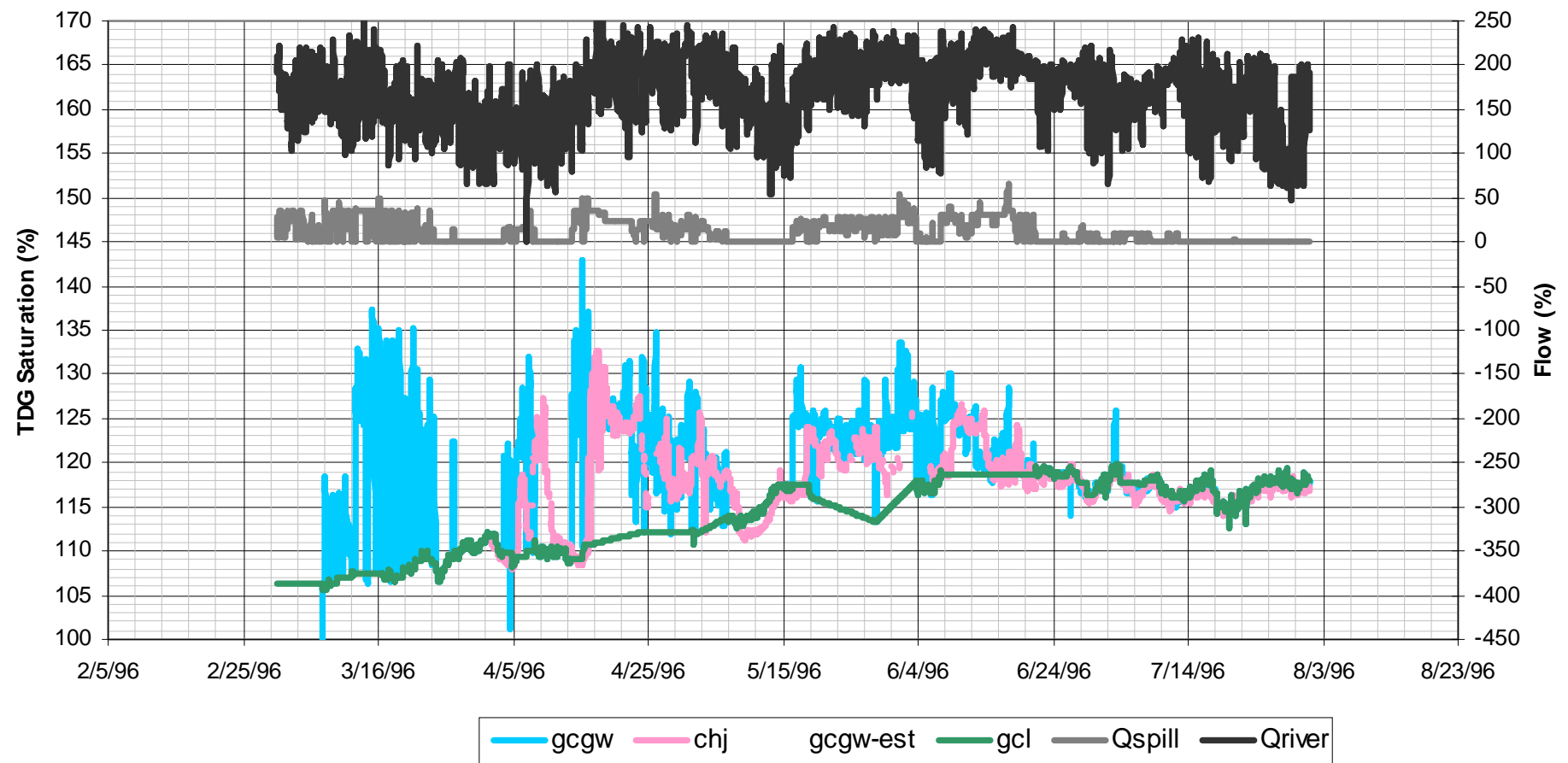
- TDG Waiver Standards
- Sampling Station Location
  - Tailwater
  - Forebay
- System Management of Spill
  - Controlled
  - Uncontrolled

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Grand Coulee Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

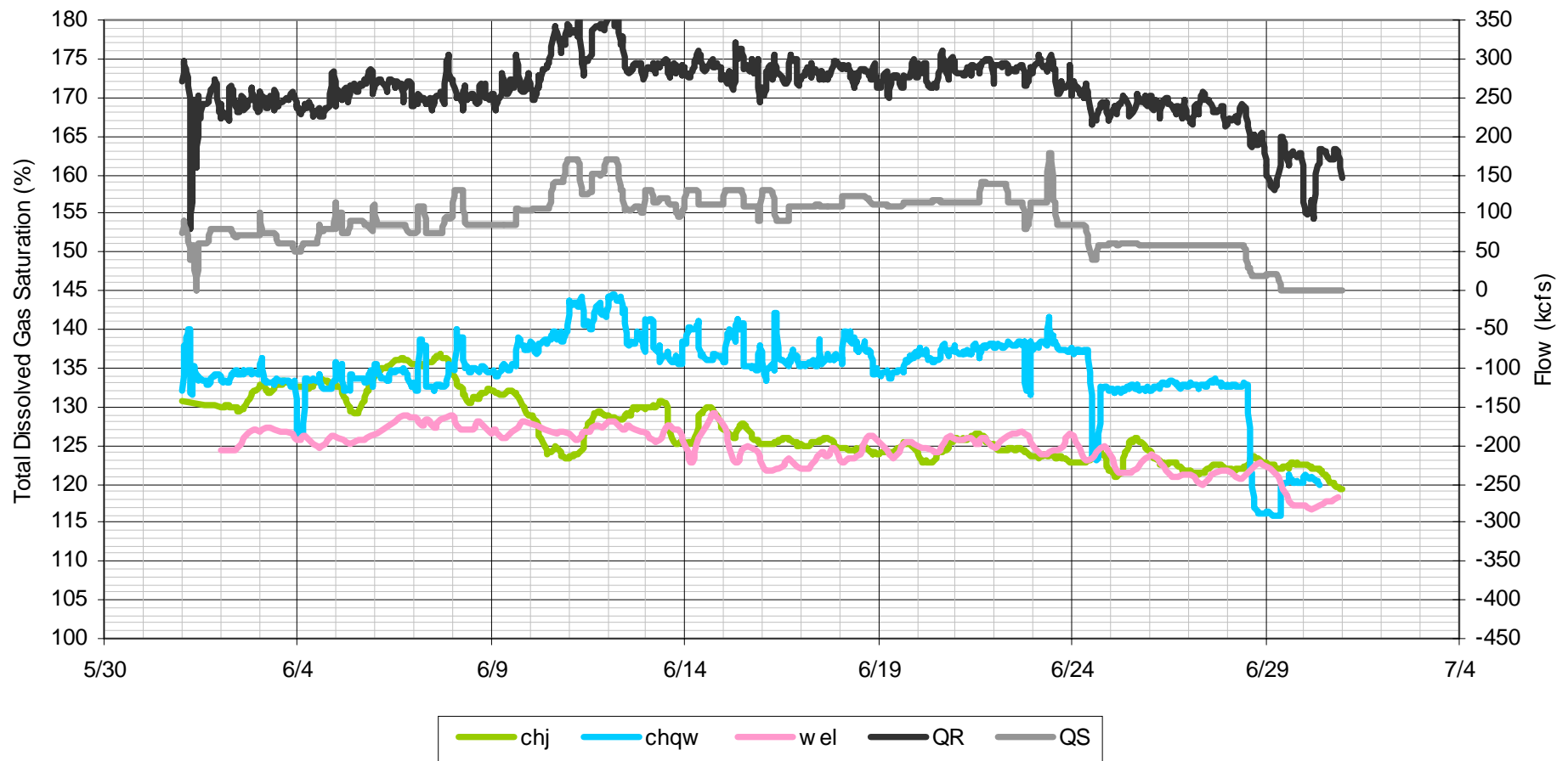


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Chief Joseph Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools



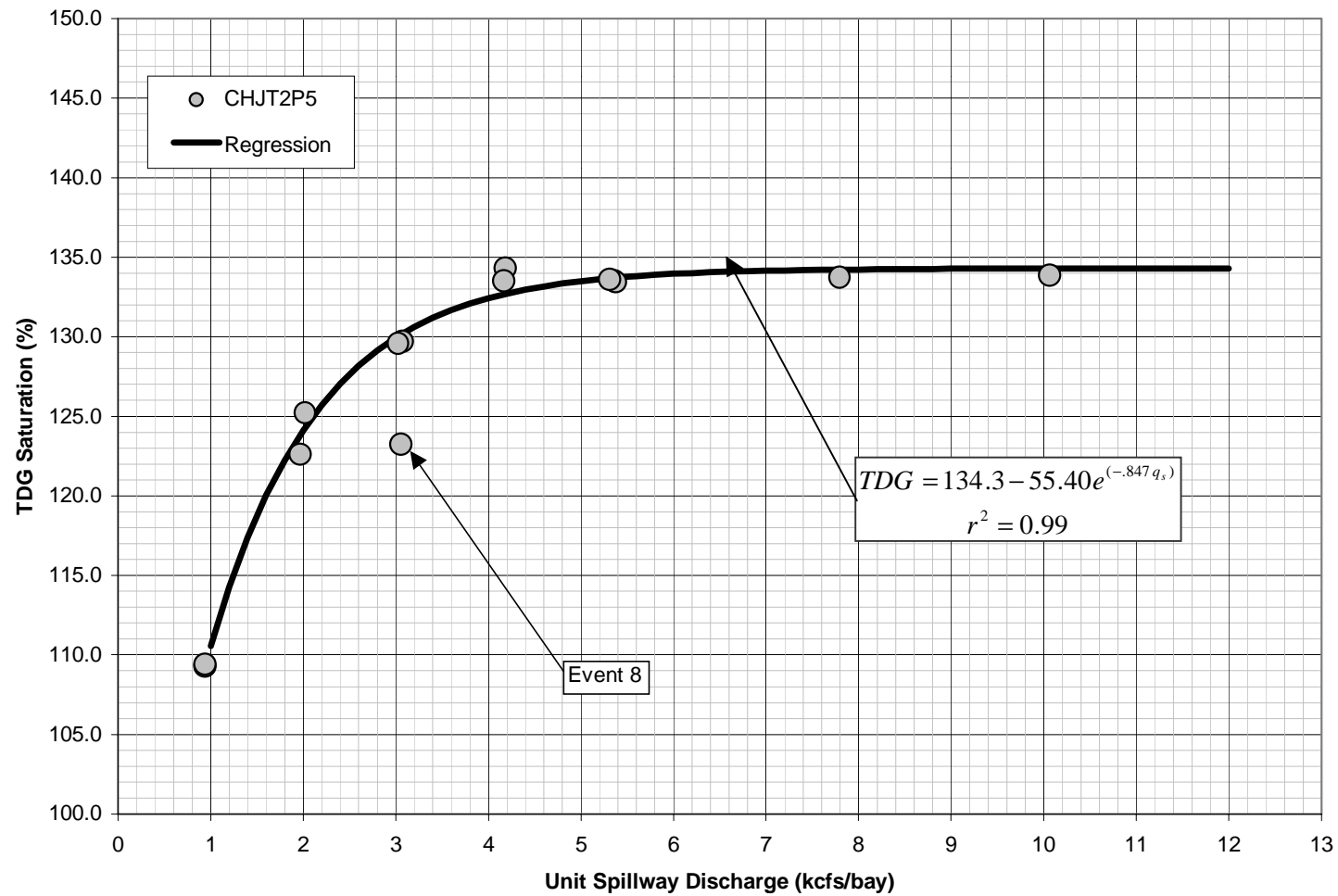
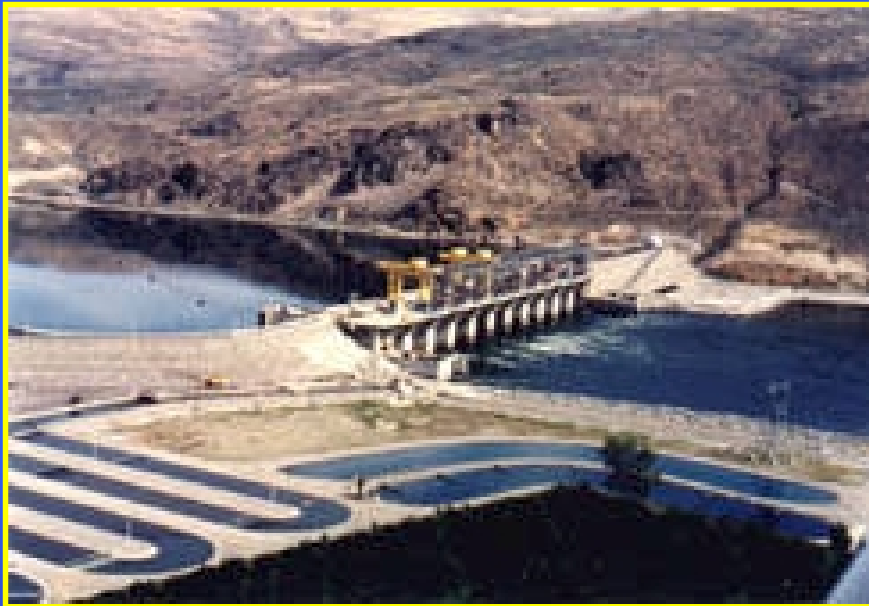


Figure 24. Total Dissolved Saturation at CHJT2P5 as a Function of Unit Spillway Discharge at Chief Joseph Dam, June 6-12, 1999.

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Wells Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Rocky Reach Dam

---



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Rocky Island Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Wanapum Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Priest Rapids Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

## Dworshak Dam

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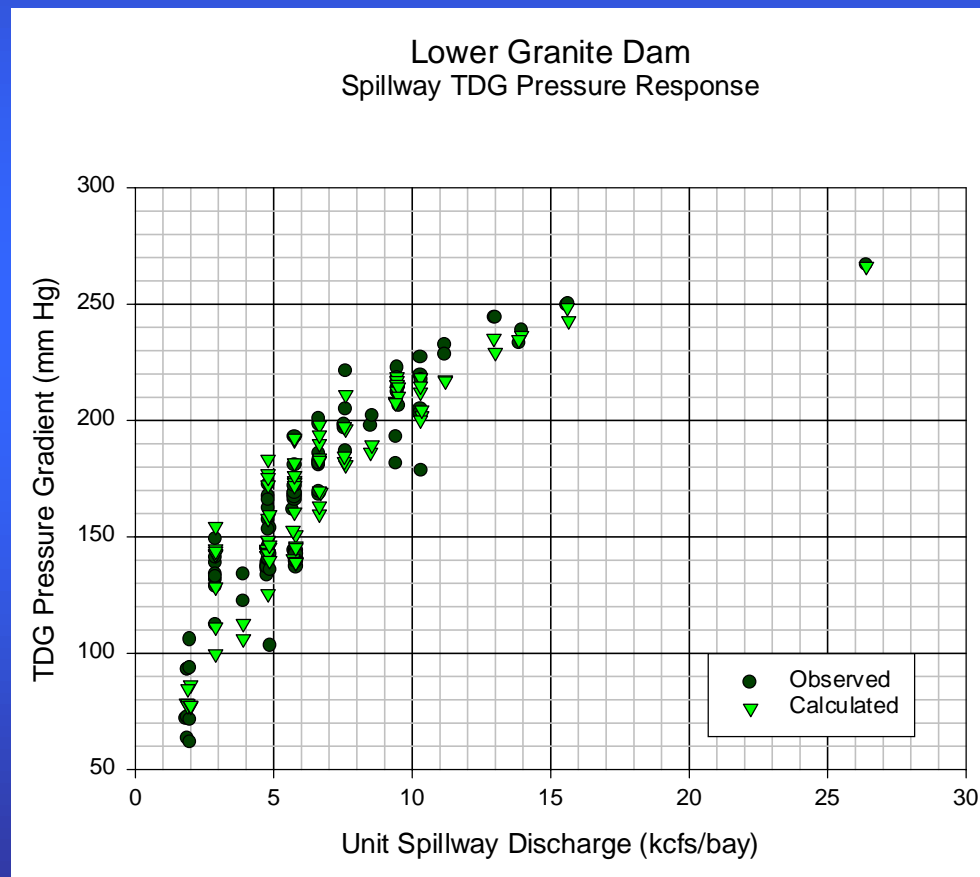


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Granite Dam

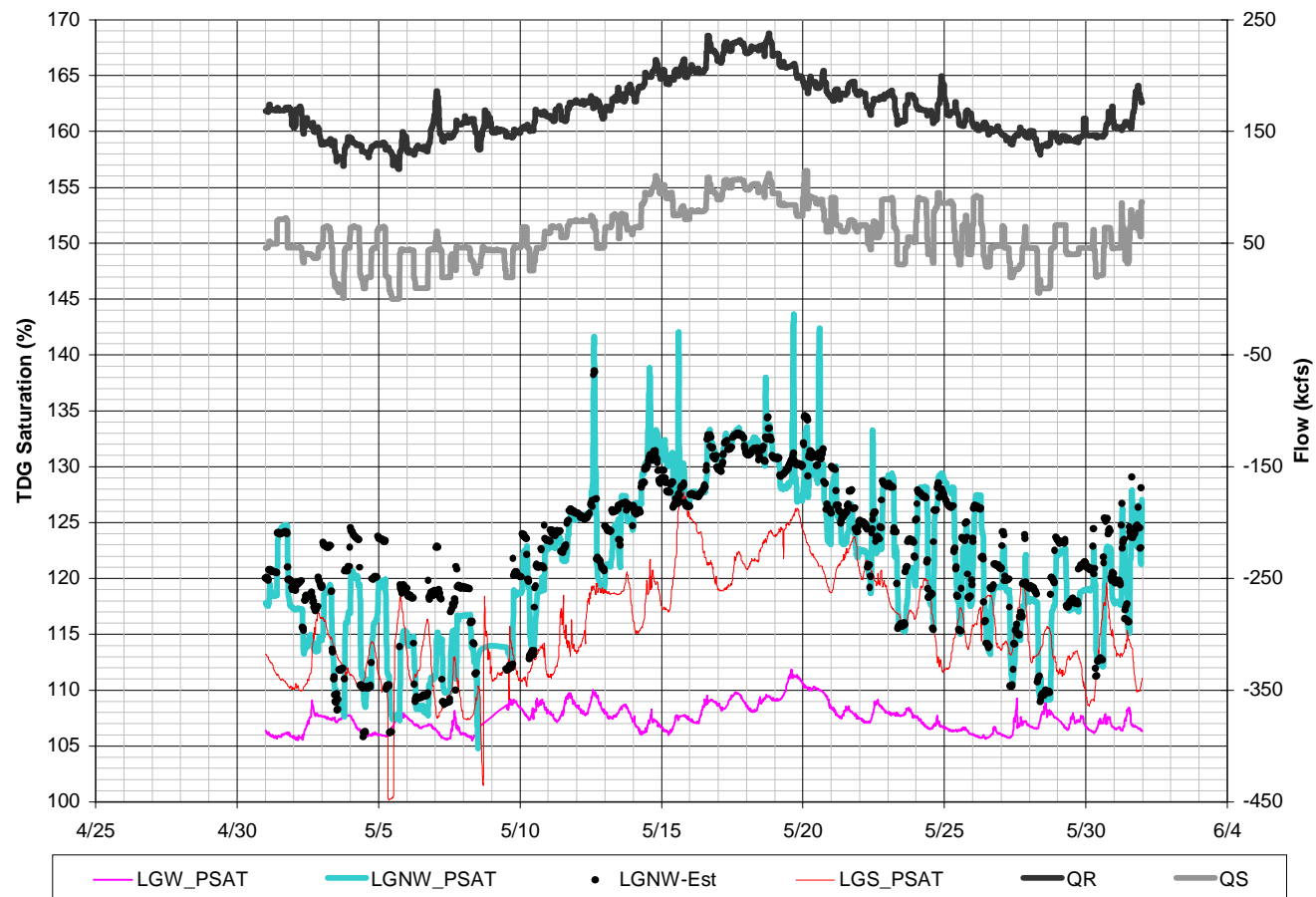
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Granite Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Granite Dam

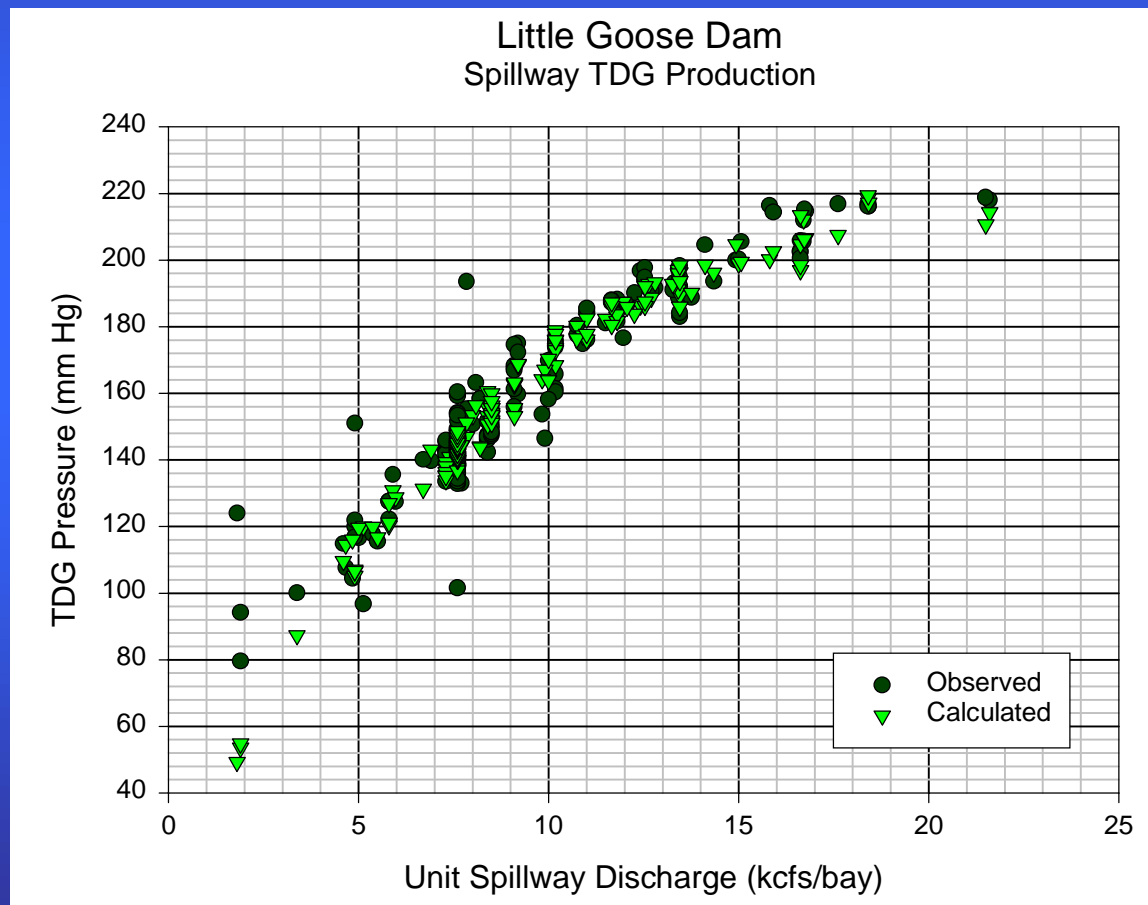


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Little Goose Dam

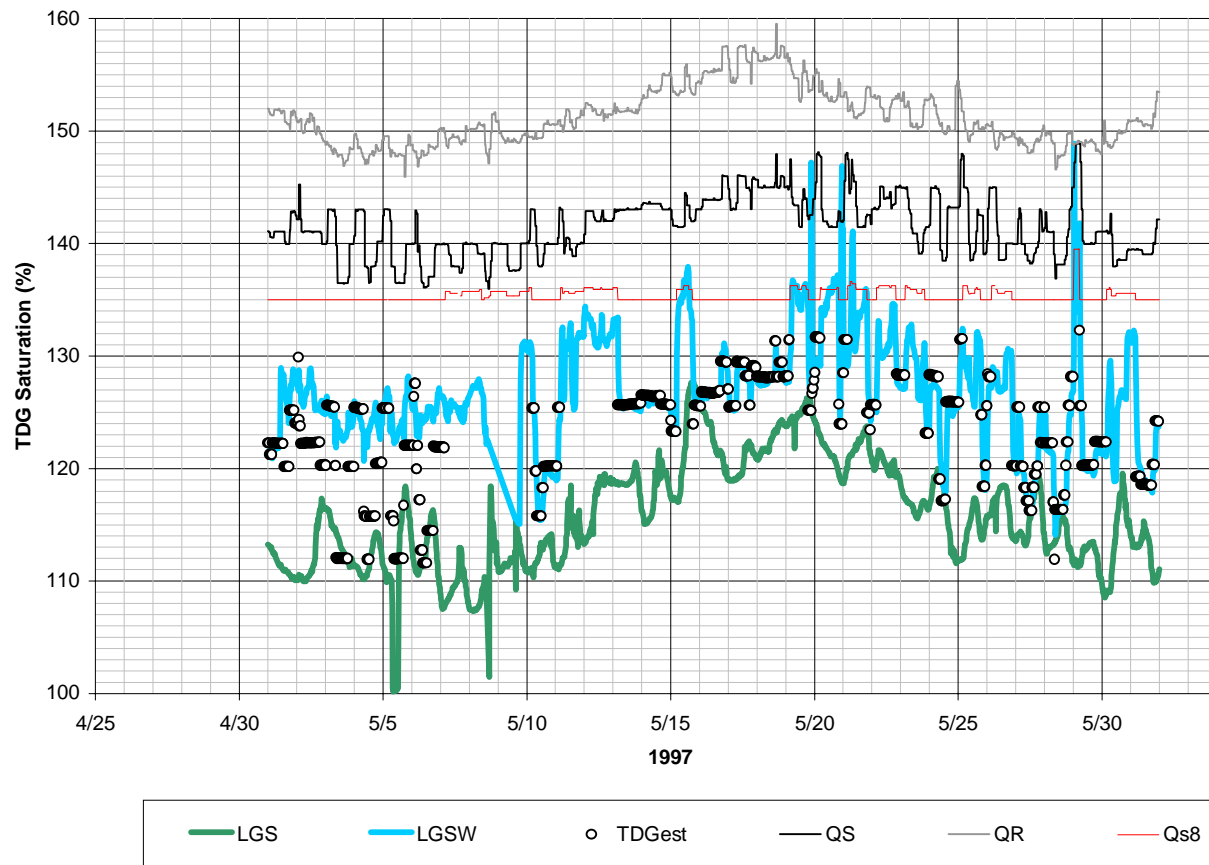
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Little Goose Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Little Goose Dam

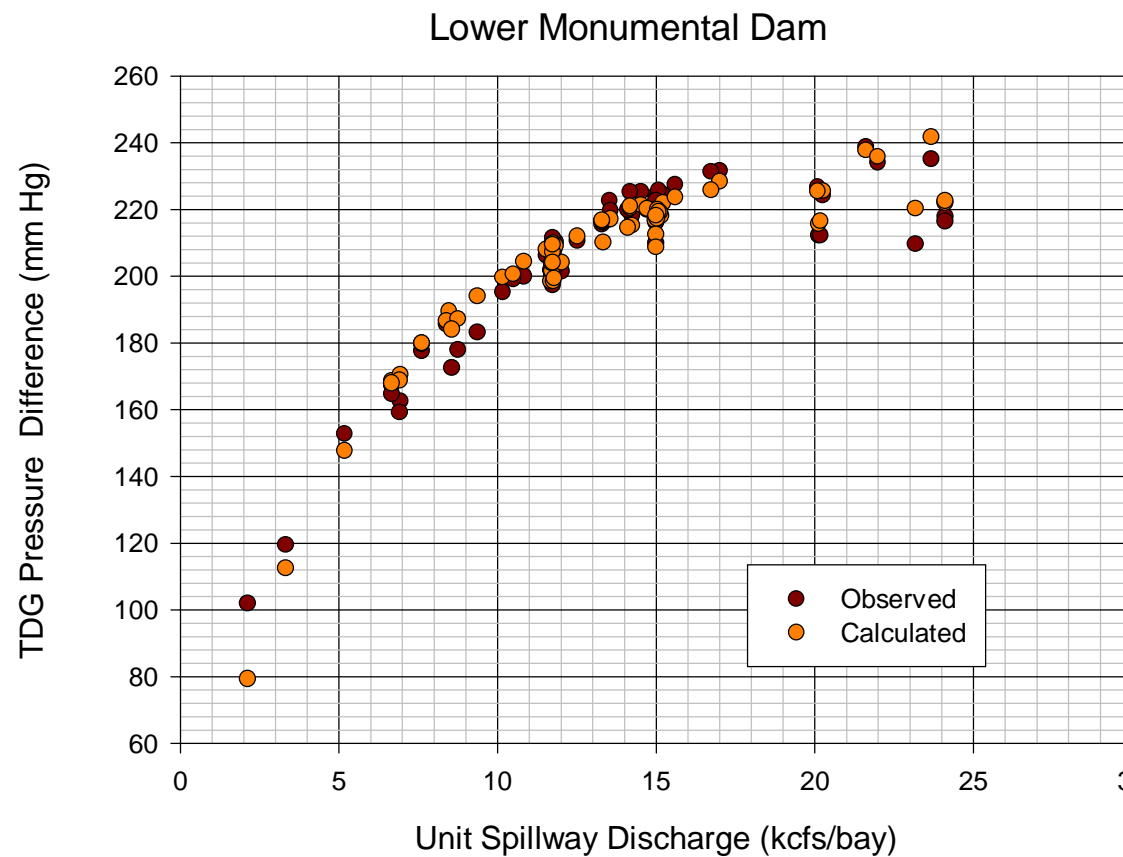


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Monumental Dam

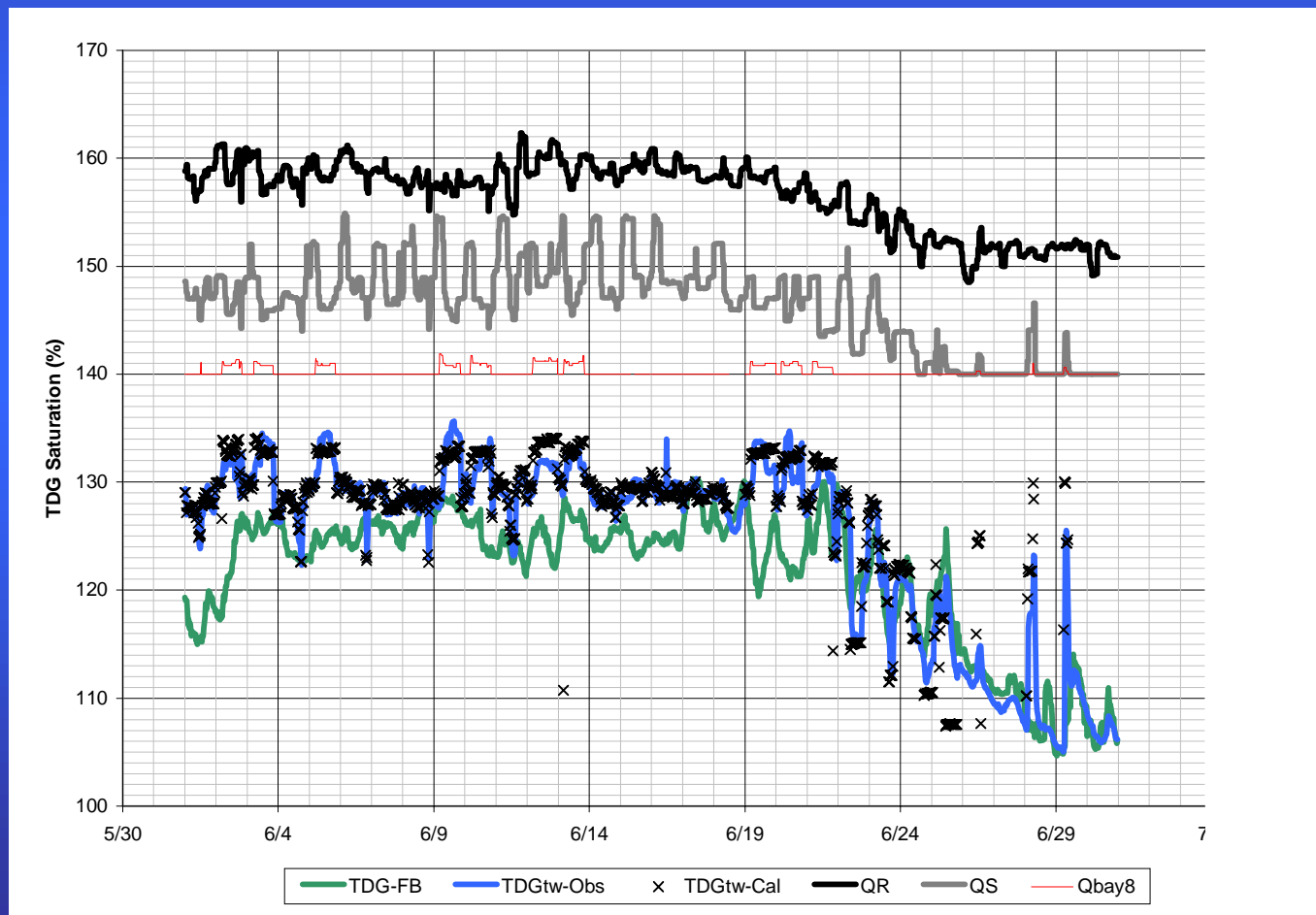
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Monumental Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Lower Monumental Dam



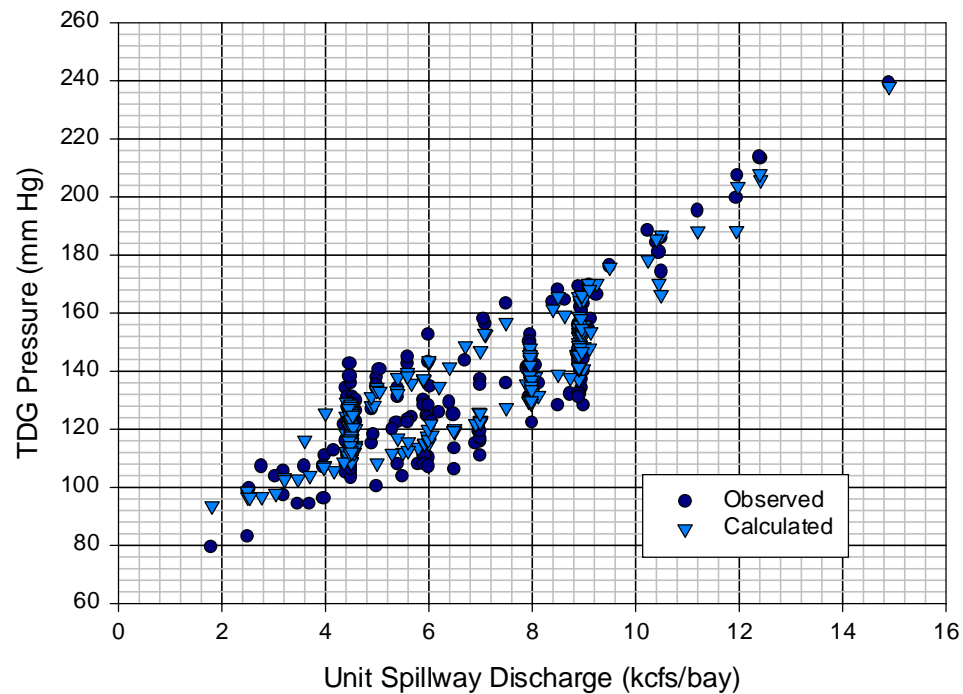
# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Ice Harbor Dam

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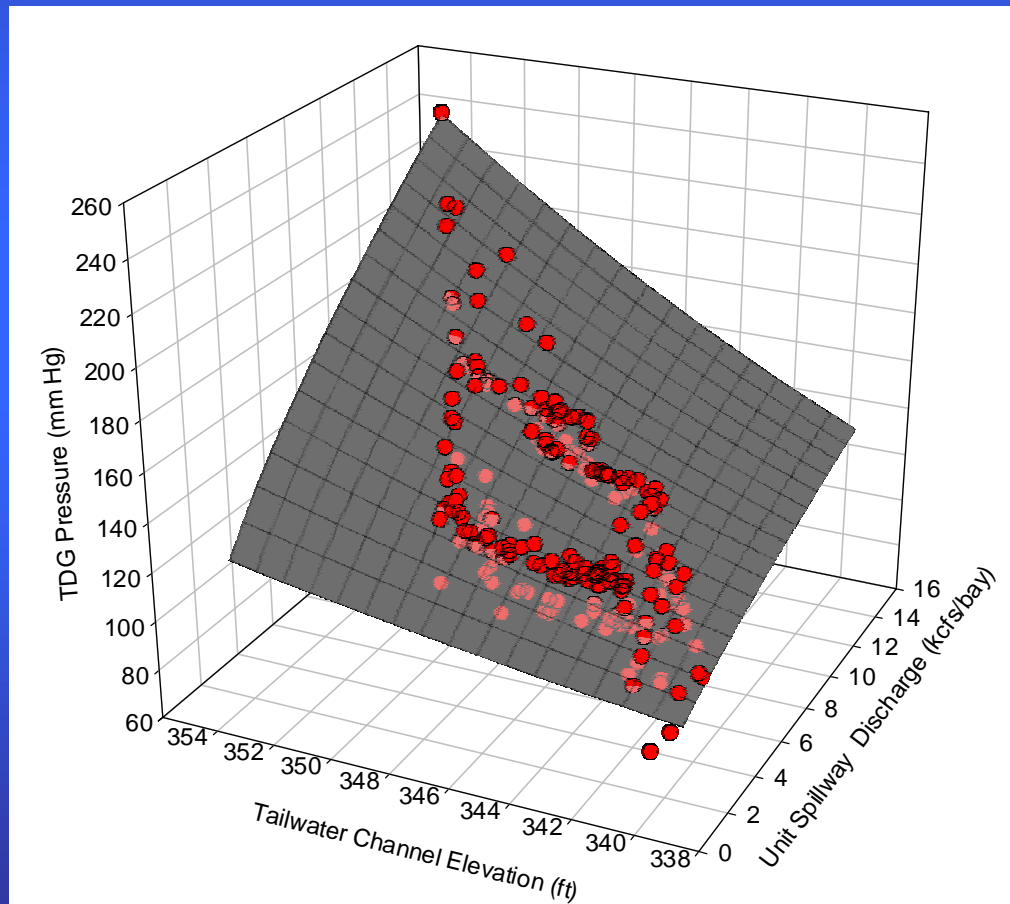
# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Ice Harbor Dam

Ice Harbor Dam  
Spillway TDG Pressure Response

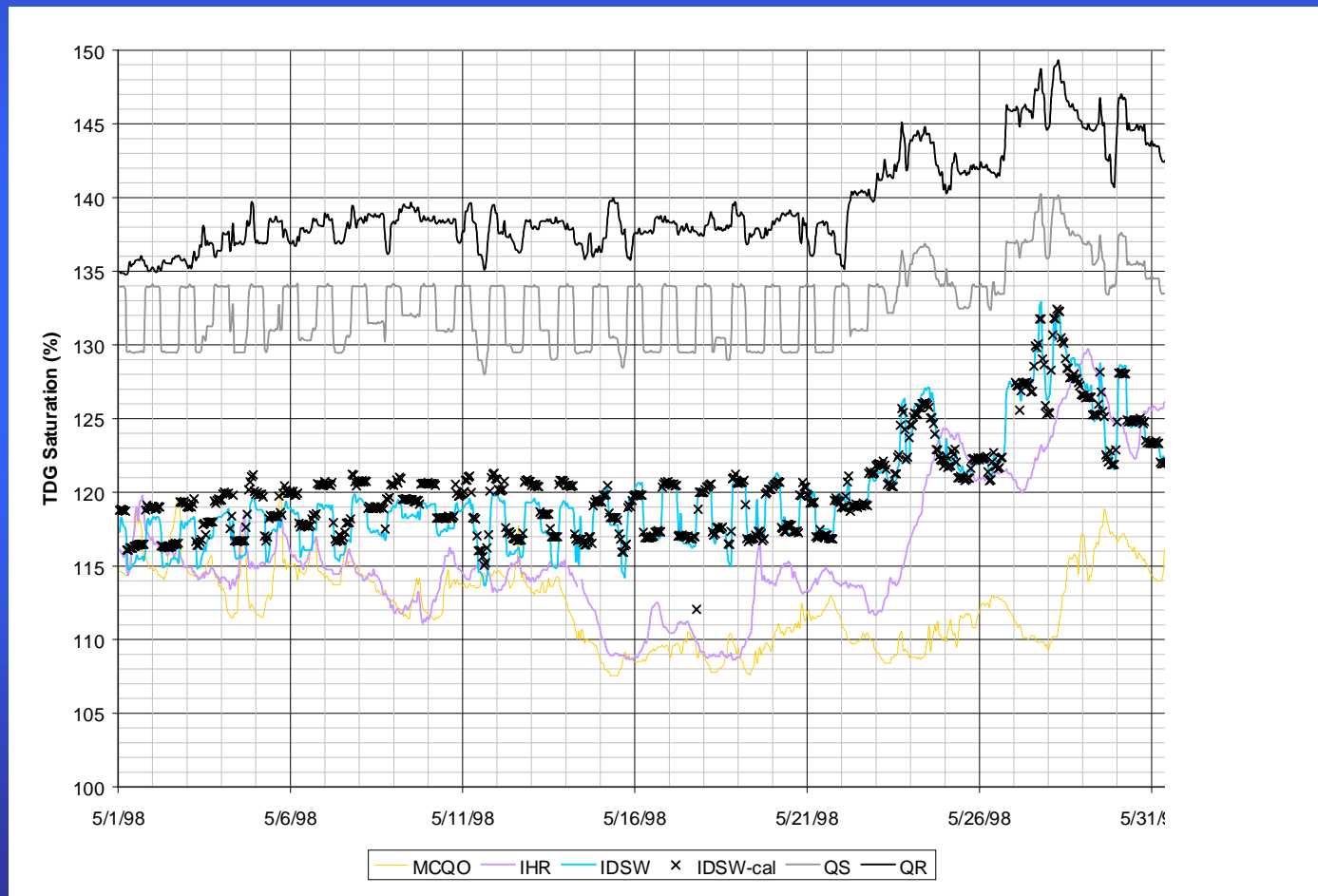


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Ice Harbor Dam

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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Ice Harbor Dam

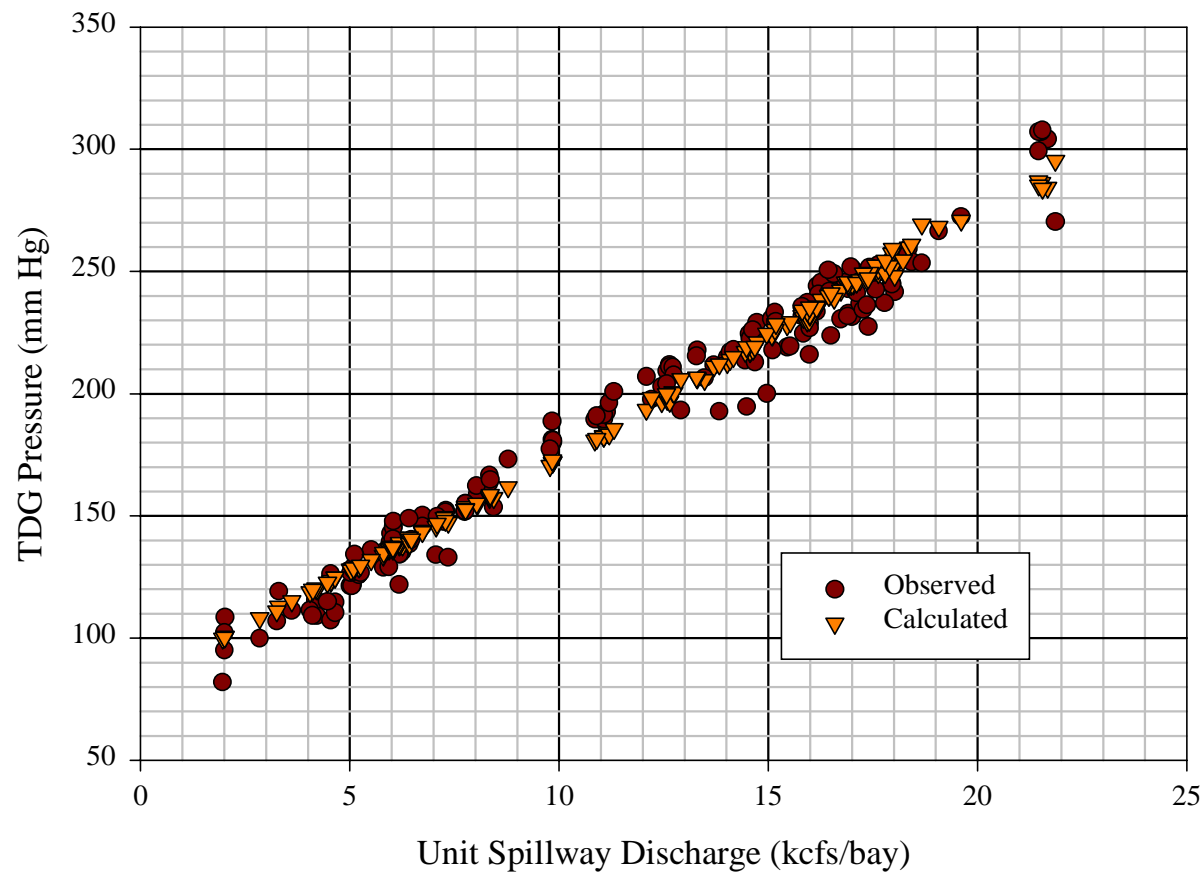


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools McNary Dam

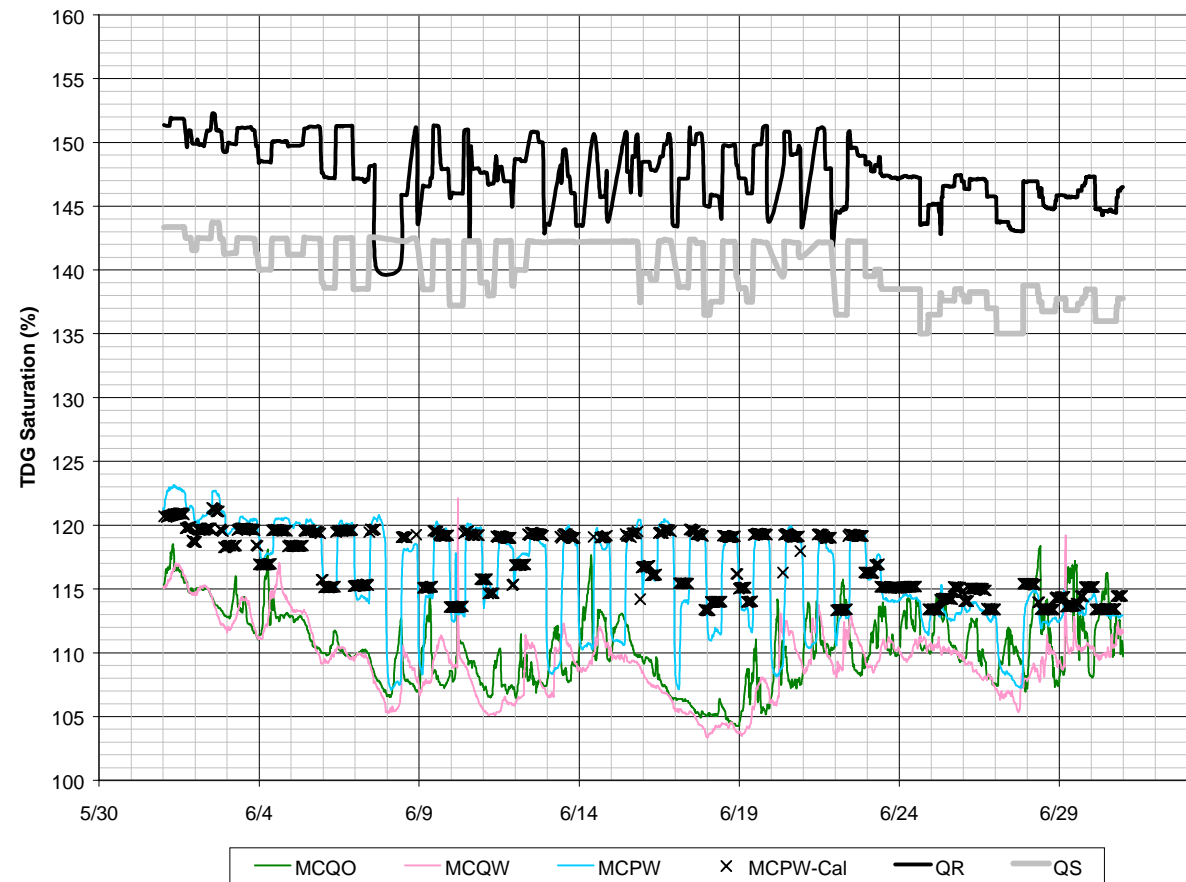
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools McNary Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools McNary Dam

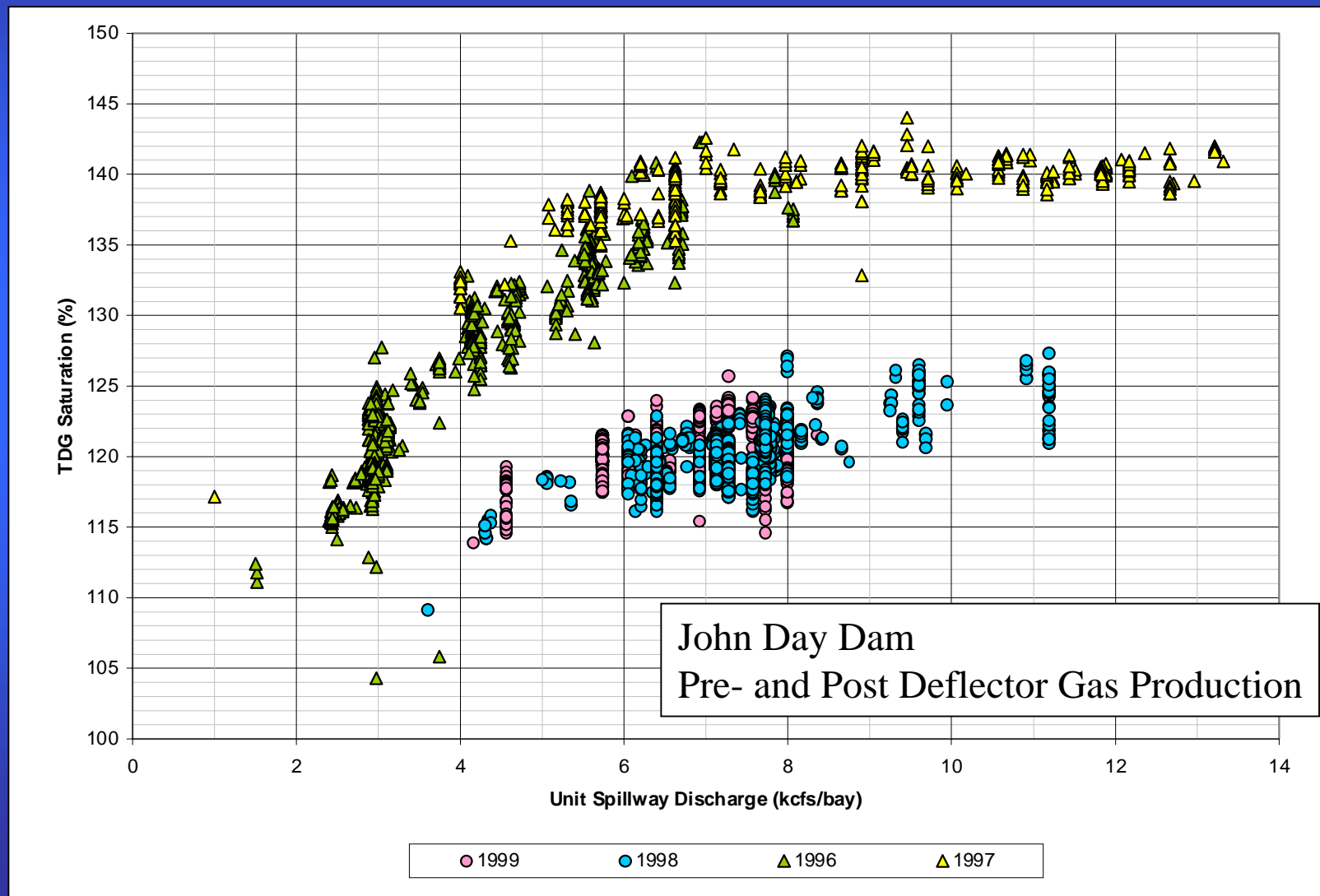


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools John Day Dam

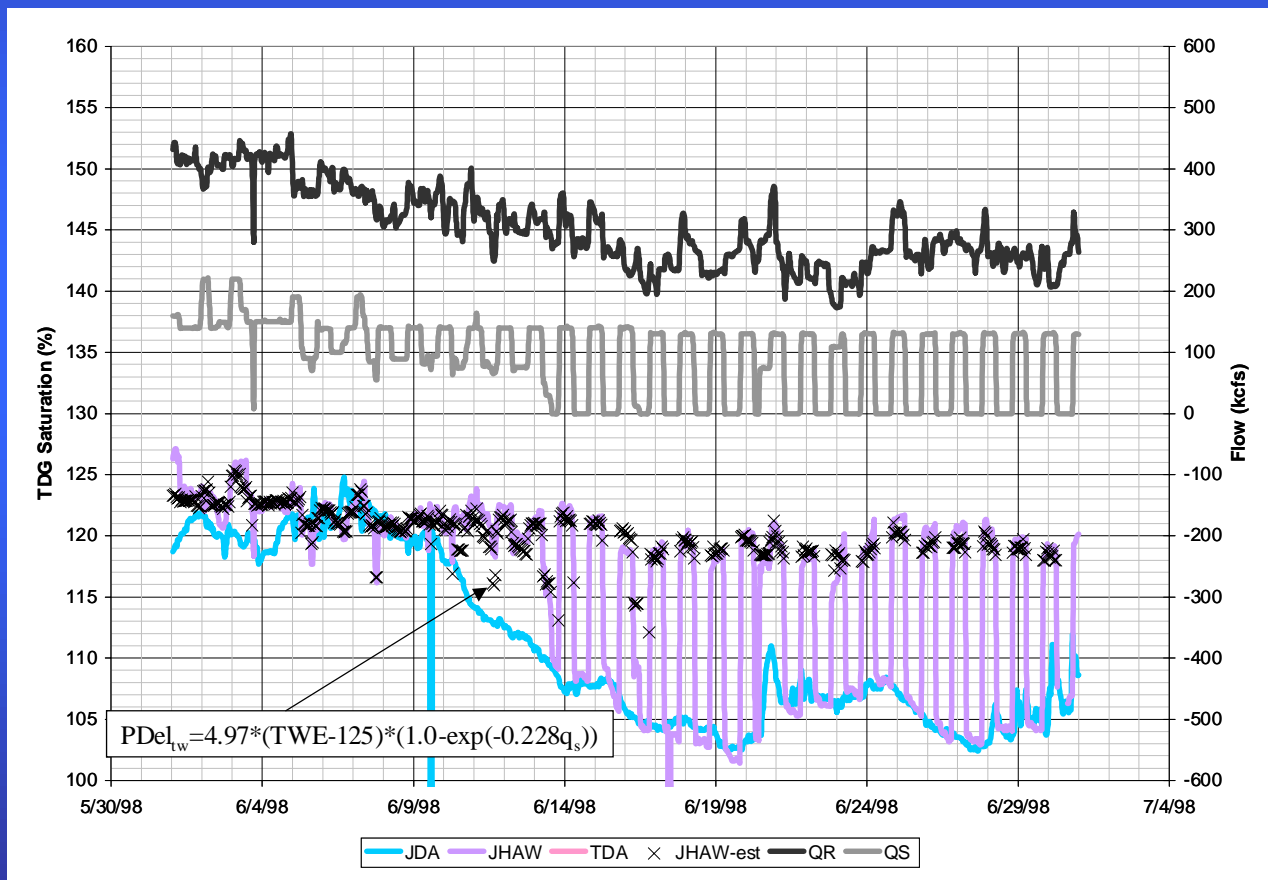
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools John Day Dam

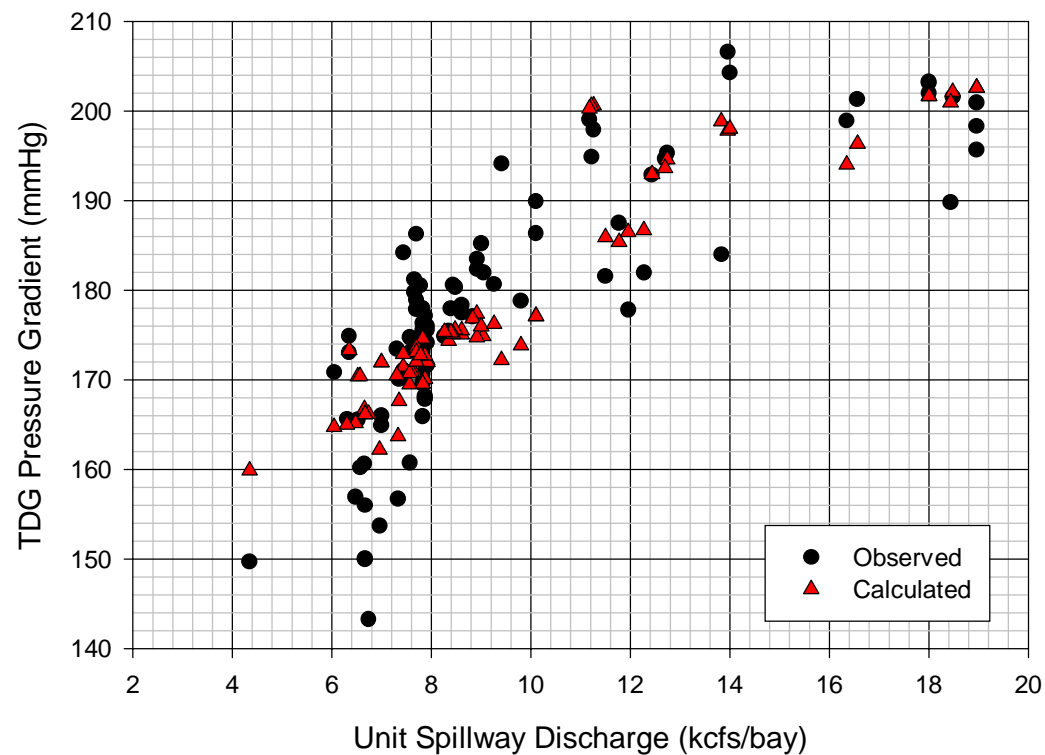


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools The Dalles Dam

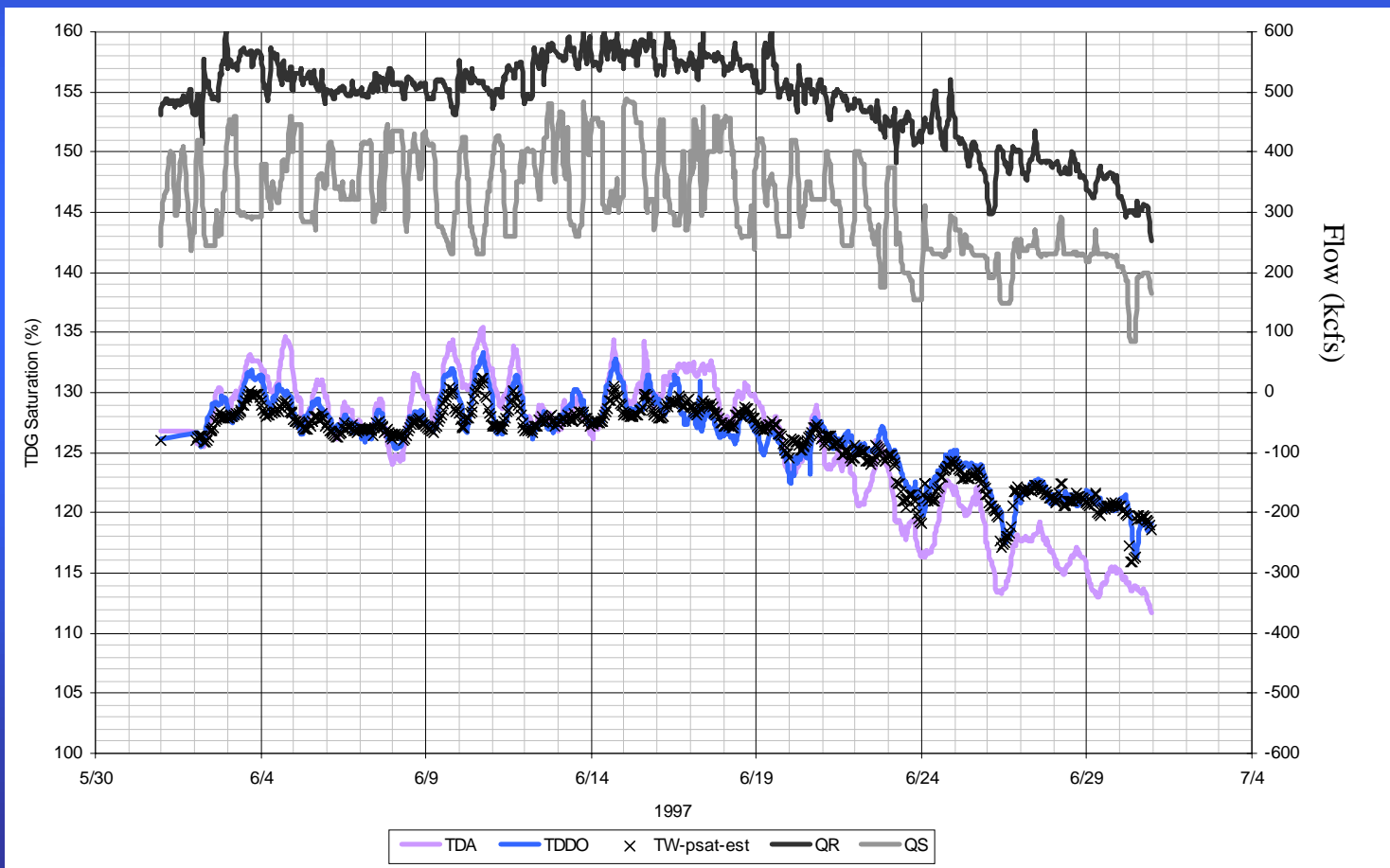
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools The Dalles Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools The Dalles Dam

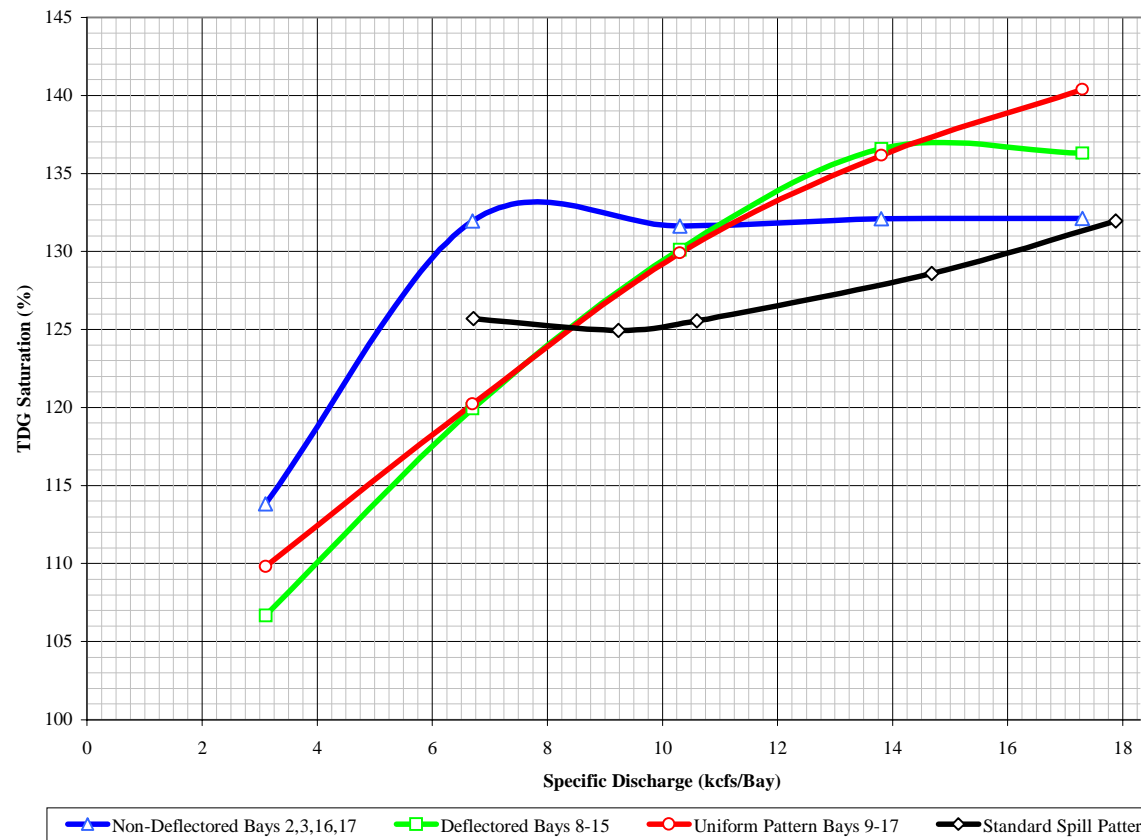


# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Bonneville Dam

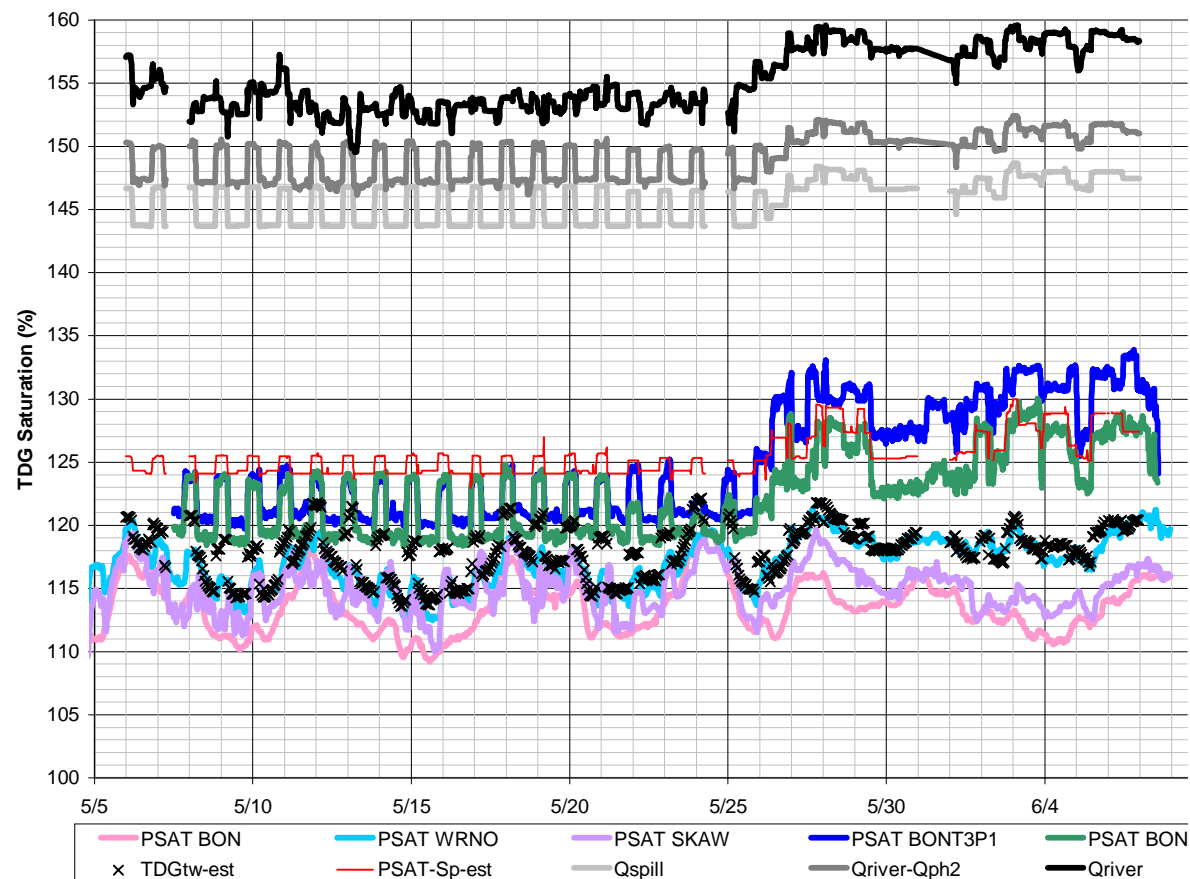
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# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Bonneville Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools Bonneville Dam



# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- TDG Models
  - Hydrodynamic and Water Quality Models
  - Governing Equations
    - Momentum, Energy, and Mass
  - Temporal and Spatial Resolution
    - 1 Dimensional
    - 2 Dimensional
  - Solution Techniques

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- SYSTDG Model Capabilities
  - Prediction/Forecasting TDG Pressures in Project Flows
    - Operational
    - Structural
    - Hydrologic Conditions
  - Process Description
  - Real Time Spill Management
    - Minimize TDG
    - Generation Constraints
  - Quality Control Fixed Monitoring System

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- **Model Limitations**
  - Not Suited for Water Control Simulations
  - Simple Transport Routine
  - No Simulation of Heat Budget
  - Spatial Resolution Limited

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- Approach

- Empirical TDG Model Developed for Each Dam
  - Intuition was used to develop the independent variables
  - Regressions used to determine equation constants
- Powerhouse and Spillway Releases Treated Separately
  - Powerhouse Flow
    - Forebay Pressures Delivered Through The Powerhouse
    - Entrainment into Bubbly Flow  $Q_e$
    - Residual  $Q_{ph} - Q_e$  Enters into the Lower Pool

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- Approach

- Spillway Flows

$$\Delta P = f(q_s, D_{tw})$$

- Composite of Deflected and Non-Deflected Bays
    - Spill Pattern - Specific Discharge ( $q_s$ )
    - Total River Flow - Tailwater Depth ( $D_{tw}$ )
    - Entrained Powerhouse Flows Acquire Spill Flow TDG Pressures

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- Approach
  - TDG Production at Dams
    - Spillway
    - Powerhouse
  - TDG Transport
    - Degassing
    - Temperature
  - Network Reaches Make up System
    - Ledger of Flow and TDG Pressure
    - Spreadsheet Basis
    - Prediction of TDG upstream and downstream of Dam

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools

---

- Approach
  - Model Input
    - Total Flow – Stage - Temperature
    - Spill Management Strategy
      - Spill Caps and Priority
      - Minimized TDG subject to System Power Need
    - Operational Parameters and Constraints
    - TDG Exchange Coefficients
  - Domain
    - Columbia River RM 120-Grand Coulee Dam
    - Snake River RM 140
  - Boundary Conditions
    - Historic TDG Loading at GCL and LGW

# Total Dissolved Gas Exchange in the Columbia River Basin: Management Tools





Execute Systdg

Time Period

Starting Date

Month 4 Day 1 Year 1996

Ending Date

Month 7 Day 31 Year 1996

Options

Run Systdg

Reset

Temperature Correction

Active Inactive

Optimization

Active Inactive

Project ID 1

Hours 50

Columbia River

Active Inactive

Upstream Project

gcl - Grand Coulee Dam

Downstream Project

chj - Chief Joseph Dam

Snake River

Active Inactive

Upstream Project

ihr - Ice Harbor Dam

Downstream Project

hdp - Ice Harbor Dam to CR

Model Execution

Model Input

Project

mcn - McNary Dam

Data

TDGfb

Initial Conditions & Model Parameters

Parameters

Show Table

Interpolate

Model Input Functions

Model Results

Display Results by Project

chj - Chief Joseph Dam

Charts

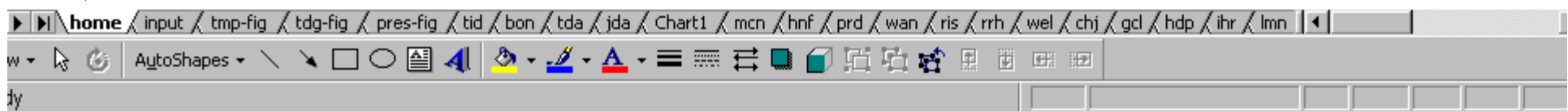
TDG Sat.

TDG Pres.

Temp.

Show Table

Model Results







J10

</

## Hourly Project Input Data - Project Worksheet

### Lower Columbia

tid - Columbia River  
 bon- Bonneville Dam  
 tda - The Dalles Dam  
 jda - John Day Dam  
 mcn - McNary Dam

### Mid-Columbia

gcl-Grand Coulee Dam  
 chj-Chief Joseph Dam  
 wel-Wells Dam  
 rrb-Rocky Reach Dam  
 ris-Rock Island Dam  
 wan-Wanapum Dam  
 prd-Priest Rapids Dam  
 hnf-Columbia River Hanford Reach

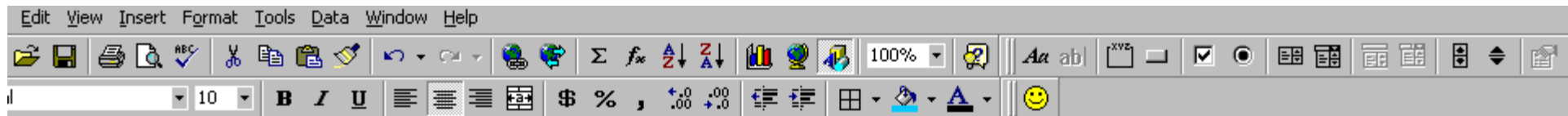
### Snake River

hdp - Snake River bl IHR  
 ihr - Ice Harbor Dam Dam  
 lmn- Lower Monumental  
 lgs - Little Goose Dam Dam  
 lwg - Lower Granite  
 clw - Clearwater River  
 dwr - Dworshak Dam

|                 |  |          |      |       |      |     |     |  |  |  |
|-----------------|--|----------|------|-------|------|-----|-----|--|--|--|
| 4/1/96 8:00 PM  |  | 16.5303  | 19.6 | 237.1 | 50.4 | 752 | 8.3 |  |  |  |
| 4/1/96 9:00 PM  |  | 17.1082  | 20.2 | 239.7 | 53.5 | 753 | 8.1 |  |  |  |
| 4/1/96 10:00 PM |  | 17.43455 | 20.5 | 236.6 | 70.7 | 755 | 7.7 |  |  |  |
| 4/1/96 11:00 PM |  | 17.262   | 20.5 | 256.9 | 70.9 | 756 | 7.9 |  |  |  |
| 4/2/96 12:00 AM |  | 16.92375 | 20.2 | 261.4 | 66.1 | 754 | 7.8 |  |  |  |
| 4/2/96 1:00 AM  |  | 17.6722  | 20.9 | 255.7 | 49.8 | 755 | 7.8 |  |  |  |
| 4/2/96 2:00 AM  |  | 17.3671  | 20.6 | 256.3 | 49.8 | 756 | 7.7 |  |  |  |
| 4/2/96 3:00 AM  |  | 17.1912  | 20.3 | 241.7 | 49.8 | 756 | 7.5 |  |  |  |

home / input / tmp-fig / tdg-fig / pres-fig / **tid** / bon / tda / jda / Chart1 / mcn / hnf / prd / wan / ris / rt





B1 = Wind

| Time            | Wind | FBE   | TWE   | Qtotal | Qspill | BP    | TMP | Qtr | TMPtr | TDGtr |
|-----------------|------|-------|-------|--------|--------|-------|-----|-----|-------|-------|
| 4/1/96 12:00 AM | 41.0 | 338.0 | 266.2 | 220.4  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 1:00 AM  | 20.0 | 338.0 | 266.2 | 220.4  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 2:00 AM  | 41.0 | 338.1 | 266.7 | 227.2  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 3:00 AM  | 0.0  | 338.1 | 266.9 | 230.8  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 4:00 AM  | 0.0  | 338.2 | 267.0 | 230.8  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 5:00 AM  | 51.0 | 338.2 | 267.0 | 230.8  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 6:00 AM  | 30.0 | 338.3 | 267.1 | 230.8  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 7:00 AM  | 20.0 | 338.3 | 267.1 | 230.8  | 67.2   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 8:00 AM  | 20.0 | 338.4 | 267.0 | 214.4  | 49.7   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 9:00 AM  | 20.0 | 338.3 | 266.9 | 213.2  | 49.7   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |
| 4/1/96 10:00 AM | 18.3 | 338.3 | 266.9 | 214.4  | 49.7   | 748.5 | 6.5 | 4.3 | 6.5   | 748.5 |

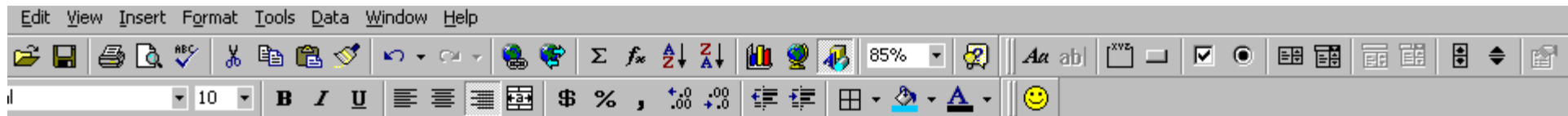
Hourly Data

### Model Input Data (Blue)

- Wind Speed (fps\*10)- Column B
- Forebay Water Surface Elevation (ft) - Column C
- Tailbay Water Surface Elevation (ft) - Column D
- Total River Flow (kcfs) - Column E
- Spillway Flow (kcfs) - Column F
- Barometric Pressure below Project - Column G
- Water Temperature at Project - Column H
- Tributary Flow (kcfs) - Column I
- Tributary Water Temperature (C) - Column J
- Tributary Total Dissolved Gas Pressure (mm Hg) - Column K

|                 |      |       |       |       |      |       |     |     |     |       |
|-----------------|------|-------|-------|-------|------|-------|-----|-----|-----|-------|
| 4/2/96 12:00 AM | 41.0 | 338.9 | 266.9 | 267.5 |      |       |     |     |     |       |
| 4/2/96 1:00 AM  | 30.0 | 338.9 | 266.9 | 258.2 |      |       |     |     |     |       |
| 4/2/96 2:00 AM  | 36.0 | 338.6 | 267.0 | 254.8 | 99.9 | 743.1 | 6.2 | 5.4 | 6.2 | 743.1 |
| 4/2/96 3:00 AM  | 30.0 | 338.5 | 267.1 | 255.3 | 99.9 | 743.3 | 6.3 | 5.4 | 6.3 | 743.3 |





B2 = 41

SYSTDG96o.xls

| A               | L     | M     | N     | O      | P      | Q      | R       | S       | T        | U       | V        | W         | X        | Y       | Z        | AA      |
|-----------------|-------|-------|-------|--------|--------|--------|---------|---------|----------|---------|----------|-----------|----------|---------|----------|---------|
| Time            | TMPfb | TDGfb | TDGsp | TDGrel | PSATfb | PSATsp | PSATrel | Qsp-est | mcqo-tmp | mcqo-bp | mcqo-tdg | mcqo-psat | mcpw-tmp | mcpw-bp | mcpw-tdg | mcpw-ps |
| 4/1/96 12:00 AM | 6.5   | 834.6 | 851.3 | 840.6  | 111.5  | 113.7  | 112.3   | 0.0     |          |         |          |           |          |         |          |         |
| 4/1/96 1:00 AM  | 6.5   | 834.2 | 851.3 | 840.3  | 111.4  | 113.7  | 112.3   | 6.4     |          |         |          |           |          |         |          |         |
| 4/1/96 2:00 AM  | 6.5   | 834.0 | 851.3 | 840.1  | 111.4  | 113.7  | 112.2   | 7.0     |          |         |          |           |          |         |          |         |
| 4/1/96 3:00 AM  | 6.5   | 833.6 | 851.3 | 839.8  | 111.4  | 113.7  | 112.2   | 6.9     |          |         |          |           |          |         |          |         |
| 4/1/96 4:00 AM  | 6.5   | 833.5 | 851.3 | 839.7  | 111.3  | 113.7  | 112.2   | 4.6     |          |         |          |           |          |         |          |         |
| 4/1/96 5:00 AM  | 6.5   | 833.4 | 851.3 | 839.6  | 111.3  | 113.7  | 112.2   | 0.9     |          |         |          |           |          |         |          |         |
| 4/1/96 6:00 AM  | 6.5   | 832.8 | 851.3 | 839.3  | 111.3  | 113.7  | 112.1   | 1.5     |          |         |          |           |          |         |          |         |
| 4/1/96 7:00 AM  | 6.5   | 832.6 | 851.3 | 839.2  | 111.2  | 113.7  | 112.1   | 0.0     |          |         |          |           |          |         |          |         |
| 4/1/96 8:00 AM  | 6.5   | 832.5 | 840.2 | 833.9  | 111.2  | 112.2  | 111.4   | 0.0     |          |         |          |           |          |         |          |         |
| 4/1/96 9:00 AM  | 6.5   | 832.5 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 0.8     |          |         |          |           |          |         |          |         |
| 4/1/96 10:00 AM | 6.5   | 832.4 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.3     |          |         |          |           |          |         |          |         |
| 4/1/96 11:00 AM | 6.5   | 832.3 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.5     |          |         |          |           |          |         |          |         |
| 4/1/96 12:00 PM | 6.5   | 832.2 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.4     | 5.7      | 743.7   | 834.6    | 112.2     |          |         |          |         |
| 4/1/96 1:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 120.    |
| 4/1/96 2:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 119.    |
| 4/1/96 3:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 119.    |
| 4/1/96 4:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 119.    |
| 4/1/96 5:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 119.    |
| 4/1/96 6:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 119.    |
| 4/1/96 7:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 118.    |
| 4/1/96 8:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/1/96 9:00 PM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/1/96 10:00 PM | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/1/96 11:00 PM | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 12:00 AM | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 1:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 121.    |
| 4/2/96 2:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 3:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 4:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 5:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 6:00 AM  | 6.4   |       |       |        |        |        |         |         |          |         |          |           |          |         |          | 122.    |
| 4/2/96 7:00 AM  | 6.4   | 829.1 | 856.7 | 840.0  | 111.2  | 114.9  | 112.7   | 13.8    | 5.5      | 748.8   | 823.8    | 110.0     | 6.6      | 753.7   | 923.7    | 122.    |
| 4/2/96 8:00 AM  | 6.4   | 828.9 | 857.2 | 840.2  | 111.1  | 114.9  | 112.6   | 12.6    | 5.5      | 749.3   | 823.3    | 109.9     | 6.7      | 754.1   | 925.5    | 122.    |
| 4/2/96 9:00 AM  | 6.4   | 828.7 | 857.8 | 840.4  | 111.0  | 114.9  | 112.5   | 12.6    | 5.5      | 750.0   | 823.2    | 109.8     | 6.8      | 754.7   | 926.5    | 122.    |
| 4/2/96 10:00 AM | 6.4   | 828.4 | 858.1 | 840.8  | 110.9  | 114.9  | 112.6   | 3.3     | 5.6      | 750.3   | 823.5    | 109.8     | 6.8      | 755.0   | 921.9    | 122.    |

### Calculated Data (Pink)

- TMPfb- Forebay Water Temperature (C) at the forebay of the current project-Column L.
- TDGfb- Total Dissolved Gas Pressure (mm Hg) at the forebay of the current project-Column M.
- TDGsp- Total Dissolved Gas Pressure (mm Hg) in spillway release only -Column N.
- TDGrel- Total Dissolved Gas Pressure (mm Hg) Average of all project releases-Column O.
- PSATfb- Total Dissolved Gas Pressure (mm Hg) at the forebay of the current project-Column P.
- PSATsp- Total Dissolved Gas Pressure (mm Hg) in spillway release only-Column Q.
- PSATrel- Total Dissolved Gas Pressure (mm Hg) Average of all project releases-Column R
- Qsp-est - Estimated Spillway Discharge (kcfs) - Column S.

home



dy

| Microsoft Excel   |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
|---|-----------------|-------|-------|-------|--------|--------|--------|---------|---------|----------|---------|----------|-----------|----------|---------|----------|
| File Edit View Insert Format Tools Data Window Help   |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
| <div> <div> </div> <div> </div> </div>  |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
| <div> <div>Arial</div> <div>10</div> <div><b>B</b></div> <div><i>I</i></div> <div><u>U</u></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> </div> |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
| B2 = 41   |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
| SYSTDG96o.xls   |                 |       |       |       |        |        |        |         |         |          |         |          |           |          |         |          |
|   | A               | L     | M     | N     | O      | P      | Q      | R       | S       | T        | U       | V        | W         | X        | Y       | Z        |
| 1   | Time            | TMPfb | TDGfb | TDGsp | TDGrel | PSATfb | PSATsp | PSATrel | Qsp-est | mcqo-tmp | mcqo-bp | mcqo-tdg | mcqo-psat | mcpw-tmp | mcpw-bp | mcpw-tdg |
| 2   | 4/1/96 12:00 AM | 6.5   | 834.6 | 851.3 | 840.6  | 111.5  | 113.7  | 112.3   | 0.0     |          |         |          |           |          |         |          |
| 3   | 4/1/96 1:00 AM  | 6.5   | 834.2 | 851.3 | 840.3  | 111.4  | 113.7  | 112.3   | 6.4     |          |         |          |           |          |         |          |
| 4   | 4/1/96 2:00 AM  | 6.5   | 834.0 | 851.3 | 840.1  | 111.4  | 113.7  | 112.2   | 7.0     |          |         |          |           |          |         |          |
| 5   | 4/1/96 3:00 AM  | 6.5   | 833.6 | 851.3 | 839.8  | 111.4  | 113.7  | 112.2   | 6.9     |          |         |          |           |          |         |          |
| 6   | 4/1/96 4:00 AM  | 6.5   | 833.5 | 851.3 | 839.7  | 111.3  | 113.7  | 112.2   | 4.6     |          |         |          |           |          |         |          |
| 7   | 4/1/96 5:00 AM  | 6.5   | 833.4 | 851.3 | 839.6  | 111.3  | 113.7  | 112.2   | 0.9     |          |         |          |           |          |         |          |
| 8   | 4/1/96 6:00 AM  | 6.5   | 832.8 | 851.3 | 839.3  | 111.3  | 113.7  | 112.1   | 1.5     |          |         |          |           |          |         |          |
| 9   | 4/1/96 7:00 AM  | 6.5   | 832.6 | 851.3 | 839.2  | 111.2  | 113.7  | 112.1   | 0.0     |          |         |          |           |          |         |          |
| 10  | 4/1/96 8:00 AM  | 6.5   | 832.5 | 840.2 | 833.9  | 111.2  | 112.2  | 111.4   | 0.0     |          |         |          |           |          |         |          |
| 11  | 4/1/96 9:00 AM  | 6.5   | 832.5 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 0.8     |          |         |          |           |          |         |          |
| 12  | 4/1/96 10:00 AM | 6.5   | 832.4 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.3     |          |         |          |           |          |         |          |
| 13  | 4/1/96 11:00 AM | 6.5   | 832.3 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.5     |          |         |          |           |          |         |          |
| 14  | 4/1/96 12:00 PM | 6.5   | 832.2 | 840.2 | 833.8  | 111.2  | 112.2  | 111.4   | 1.4     | 5.7      | 743.7   | 834.6    | 112.2     |          |         |          |
| 15  | 4/1/96 1:00 PM  | 6.4   | 832.2 | 840.2 | 833.7  | 111.2  | 112.2  | 111.4   | 7.2     | 5.7      | 743.8   | 834.5    | 112.2     | 6.5      | 748.5   | 897.9    |
| 16  | 4/1/96 2:00 PM  | 6.4   | 832.1 | 832.1 | 830.2  | 112.4  | 112.4  | 112.1   | 6.6     | 5.8      | 743.7   | 837.2    | 112.6     | 6.6      | 748.3   | 894.3    |
| 17  | 4/1/96 3:00 PM  | 6.4   | 832.0 | 831.6 | 829.9  | 112.4  | 112.4  | 112.2   | 6.6     | 5.9      | 743.2   | 837.8    | 112.7     | 6.7      | 747.7   | 893.0    |
| 18  | 4/1/96 4:00 PM  | 6.4   | 831.9 | 831.7 | 829.9  | 112.4  | 112.4  | 112.1   | 6.6     | 6.0      | 743.5   | 840.3    | 113.0     | 6.7      | 747.7   | 890.5    |
| 19  | 4/1/96 5:00 PM  | 6.4   | 831.7 | 831.8 | 829.8  | 112.4  | 112.4  | 112.1   | 5.9     | 6.2      | 743.5   | 842.9    | 113.4     | 6.7      | 747.6   | 890.2    |
| 20  | 4/1/96 6:00 PM  | 6.4   | 831.2 | 831.7 | 829.6  | 112.3  | 112.4  | 112.1   | 1.2     | 6.3      | 743.5   | 843.4    | 113.4     | 6.6      | 747.6   | 890.4    |
| 21  | 4/1/96 7:00 PM  | 6.4   | 831.1 | 831.9 |        |        |        |         |         |          |         |          |           |          |         | 888.7    |
| 22  | 4/1/96 8:00 PM  | 6.4   | 831.0 | 863.4 |        |        |        |         |         |          |         |          |           |          |         | 914.1    |
| 23  | 4/1/96 9:00 PM  | 6.4   | 830.8 | 863.9 |        |        |        |         |         |          |         |          |           |          |         | 916.4    |
| 24  | 4/1/96 10:00 PM | 6.4   | 830.6 | 864.2 |        |        |        |         |         |          |         |          |           |          |         | 915.9    |
| 25  | 4/1/96 11:00 PM | 6.4   | 830.5 | 864.9 |        |        |        |         |         |          |         |          |           |          |         | 916.5    |
| 26  | 4/2/96 12:00 AM | 6.4   | 830.3 | 865.4 |        |        |        |         |         |          |         |          |           |          |         | 916.5    |
| 27  | 4/2/96 1:00 AM  | 6.4   | 830.0 | 865.3 |        |        |        |         |         |          |         |          |           |          |         | 913.2    |
| 28  | 4/2/96 2:00 AM  | 6.4   | 829.9 | 865.9 |        |        |        |         |         |          |         |          |           |          |         | 916.2    |
| 29  | 4/2/96 3:00 AM  | 6.4   | 829.7 | 866.0 |        |        |        |         |         |          |         |          |           |          |         | 920.9    |
| 30  | 4/2/96 4:00 AM  | 6.4   | 829.6 | 866.3 |        |        |        |         |         |          |         |          |           |          |         | 922.4    |
| 31  | 4/2/96 5:00 AM  | 6.4   | 829.5 | 866.9 |        |        |        |         |         |          |         |          |           |          |         | 924.1    |
| 32  | 4/2/96 6:00 AM  | 6.4   | 829.2 | 855.9 |        |        |        |         |         |          |         |          |           |          |         | 922.0    |
| 33  | 4/2/96 7:00 AM  | 6.4   | 829.1 | 856.7 |        |        |        |         |         |          |         |          |           |          |         | 923.7    |
| 34  | 4/2/96 8:00 AM  | 6.4   | 828.9 | 857.2 |        |        |        |         |         |          |         |          |           |          |         | 925.5    |
| 35  | 4/2/96 9:00 AM  | 6.4   | 828.7 | 857.8 |        |        |        |         |         |          |         |          |           |          |         | 926.5    |
| 36  | 4/2/96 10:00 AM | 6.4   | 828.4 | 858.1 | 840.8  | 110.9  | 114.9  | 112.6   | 3.3     | 5.6      | 750.3   | 823.5    | 109.8     | 6.8      | 755.0   | 921.9    |

**Fixed Monitoring Station Observed Water Quality Data (Tan)**

Forebay FMS Temperature (C) - Column T

Forebay FMS Barometric Pressure-Column U

Forebay FMS Total Dissolved Gas Pressure- Column V

Forebay FMS Total Dissolved Gas Saturation - Column W

Tailwater FMS Temperature (C) - Column X

Tailwater FMS Barometric Pressure-Column Y

Tailwater FMS Total Dissolved Gas Pressure- Column Z

Tailwater FMS Total Dissolved Gas Saturation - Column AA

Optimization Worksheet

Weight Factors

Objective Function

Decision Variables

Power Constraint

|                                   | A       | B    | C    | D    | E    | F    | G    | H    | I   | J    | K    | L    | M    | N   | O    | P   | Q    | R    | S    | T    | U   | V       | W       |
|-----------------------------------|---------|------|------|------|------|------|------|------|-----|------|------|------|------|-----|------|-----|------|------|------|------|-----|---------|---------|
|                                   | Project | GCL  | CHJ  | WEL  | RRH  | RIS  | WAN  | PRD  | HNF | MCN  | JDA  | TDA  | BON  | TID | DWR  | CLW | LWG  | LGS  | LMN  | IHR  | HDP |         |         |
| Weight Factor                     |         | 1    | 1    | 1    | 1    | 1    | 1    | 1    |     | 1    | 1    | 1    | 1    |     | 0    |     | 1    | 1    | 1    | 1    |     |         | *       |
| Qriver (kcfs)                     |         | 112  | 101  | 129  | 137  | 141  | 132  | 134  |     | 219  | 237  | 240  | 242  |     | 8.3  |     | 89.2 | 93.5 | 90.1 | 97.2 |     |         |         |
| FBE (ft)                          |         | 1243 | 955  | 780  | 706  | 613  | 570  | 486  |     | 339  | 264  | 159  | 74.6 |     | 1504 |     | 734  | 636  | 538  | 439  |     |         |         |
| TWE (ft)                          |         | 964  | 782  | 713  | 619  | 573  | 492  | 410  |     | 267  | 162  | 80   | 20.7 |     | 977  |     | 636  | 539  | 442  | 346  |     |         |         |
| Total Head (ft)                   |         | 279  | 172  | 66.5 | 87.4 | 39.8 | 77.7 | 76.4 |     | 72   | 102  | 78.5 | 53.9 |     | 527  |     | 98.3 | 96.7 | 96.4 | 92.5 |     |         |         |
| Generation Fraction (Qph/Qriver)  |         | 1    | 0.84 | 0.96 | 0.88 | 0.92 | 0.89 | 0.9  |     | 0.99 | 0.89 | 0.98 | 1    |     | 0.48 |     | 0.88 | 0.79 | 0.73 | 0.84 |     |         |         |
| Qspill (kcfs)                     |         | 0.34 | 16.4 | 5.53 | 16.1 | 11   | 14.7 | 12.8 |     | 1.79 | 25.3 | 5.28 | 0    |     | 4.28 |     | 10.4 | 19.9 | 24.7 | 15.2 |     |         |         |
| Qph (kcfs)                        |         | 112  | 84.6 | 123  | 121  | 130  | 117  | 121  |     | 217  | 212  | 235  | 242  |     | 4.02 |     | 78.8 | 73.6 | 65.4 | 82   |     |         |         |
| Qentrainment (kcfs)               |         | 0.46 | 0    | 0    | 0    | 0    | 0    | 0    |     | 35   | 0    | 0    | 0    |     |      |     | 7.79 | 19.9 |      |      |     |         |         |
| Barometric Pressure (mm Hg)       |         | 744  | 743  | 740  | 739  | 751  | 750  | 757  |     | 752  | 755  | 758  | 763  |     | 739  |     | 743  | 751  |      |      |     |         |         |
| TDG Pressure - Spillway (mm Hg)   |         | 1099 | 854  | 772  | 865  | 974  | 965  | 828  |     | 811  | 743  | 912  | 861  |     |      |     | 788  | 826  | 855  | 841  |     |         |         |
| TDG Pressure - Powerhouse (mm Hg) |         | 816  | 805  | 816  | 802  | 800  | 802  | 802  |     | 823  | 895  | 832  | 861  |     | 0    |     | 780  | 780  | 780  | 767  |     |         |         |
| TDG Pressure - Project            |         | 818  | 813  | 814  | 809  | 814  | 820  | 805  |     | 821  | 878  | 834  | 861  |     | 0    |     | 781  | 800  | 802  | 779  |     |         |         |
| TDG Saturation - Spillway (%)     |         | 148  | 115  | 104  | 117  | 130  | 129  | 109  |     | 108  | 98.5 | 120  | 113  |     | 0    |     | 106  | 110  | 113  | 112  |     |         |         |
| TDG Saturation - Powerhouse (%)   |         | 110  | 108  | 110  | 108  | 107  | 107  | 106  |     | 109  | 118  | 110  | 113  |     | 0    |     | 105  | 104  | 103  | 102  |     |         |         |
| TDG Saturation - Project (%)      |         | 110  | 109  | 110  | 109  | 108  | 109  | 106  |     | 109  | 116  | 110  | 113  |     | 0    |     | 105  | 106  | 106  | 103  |     |         |         |
| Target TDG Saturation             |         | 110  | 110  | 110  | 110  | 110  | 110  | 110  |     | 110  | 110  | 110  | 110  |     | 110  |     | 110  | 110  | 110  | 110  |     |         |         |
| Exceedence of TDG Target          |         | 0    | 0    | 0.03 | 0    | 0    | 0    | 0    |     | 0    | 6.35 | 0    | 2.79 |     | 0    |     | 0    | 0    | 0    | 0    |     | 48.1375 |         |
| Net Generation (MW)               |         | 2302 | 1029 | 542  | 834  | 404  | 712  | 729  |     | 1082 | 1570 | 1360 | 948  |     | 171  |     | 576  | 517  | 458  | 568  |     | 13804   | 13803.6 |
| Generation Capacity (MW)          |         | 2309 | 1229 | 566  | 945  | 438  | 802  | 806  |     | 1091 | 1758 | 1391 | 948  |     | 354  |     | 652  | 657  | 631  | 673  |     | 15250   |         |
| Estimated Qspill (kcfs)           |         | 0.34 | 16.4 | 5.53 | 16.1 | 11   | 14.7 | 12.8 |     | 1.79 | 25.3 | 5.28 | 0    |     | 4.28 |     | 10.4 | 19.9 | 24.7 | 15.2 |     |         |         |
| Historic Qspill (kcfs)            |         | 0    | 0    | 0    | 0    | 0    | 0    | 0    |     | 49.7 | 4.7  | 60   | 71.3 |     | 0    |     | 20.7 | 15.1 | 10.2 | 30   |     |         |         |
| Historic Qpowerhouse (kcfs)       |         | 112  | 101  | 129  | 137  | 141  | 132  | 134  |     | 169  | 232  | 180  | 170  |     | 8.3  |     | 68.5 | 78.4 | 79.9 | 67.2 |     |         |         |
| Historic MW                       |         | 2309 | 1229 | 566  | 945  | 438  | 802  | 806  |     | 842  | 1723 | 1044 | 668  |     | 354  |     | 501  | 551  | 559  | 466  |     | 13803.6 |         |

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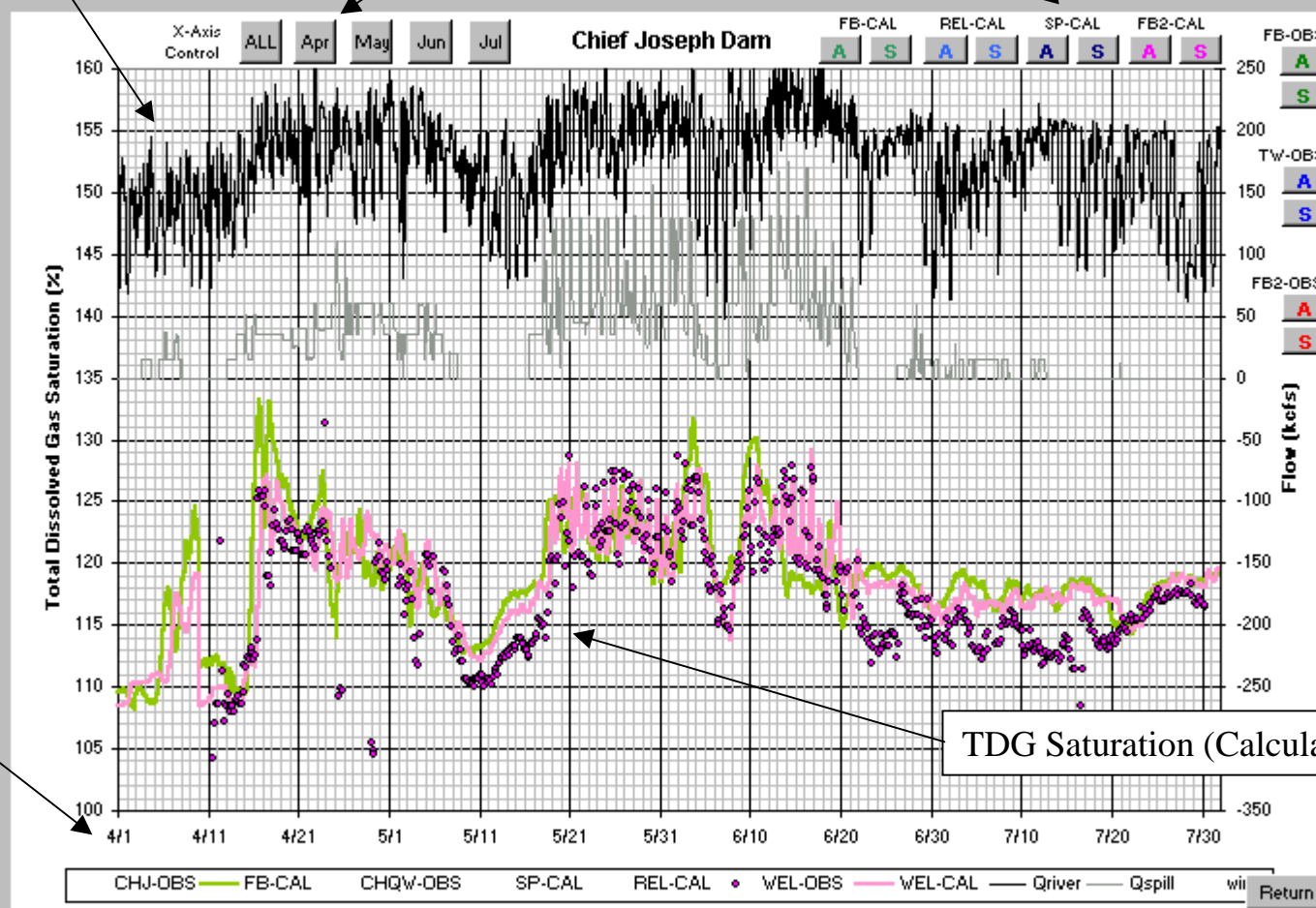
Graph of Model and Observed Data  
(worksheet page tdg-fig)

Operations Data Qriver and Qspill

X-axis Controls

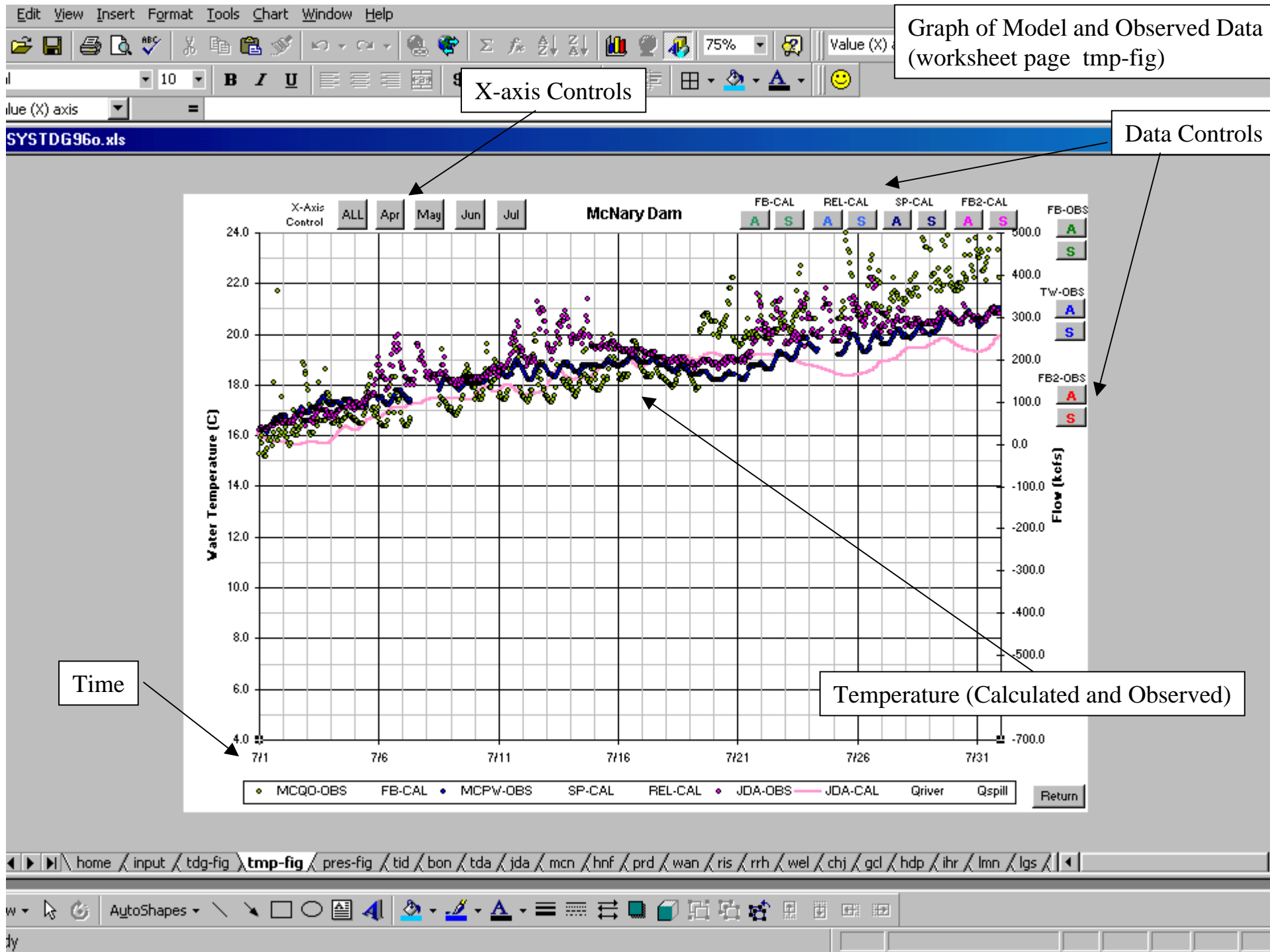
Data Controls

SYSTDG96o.xls



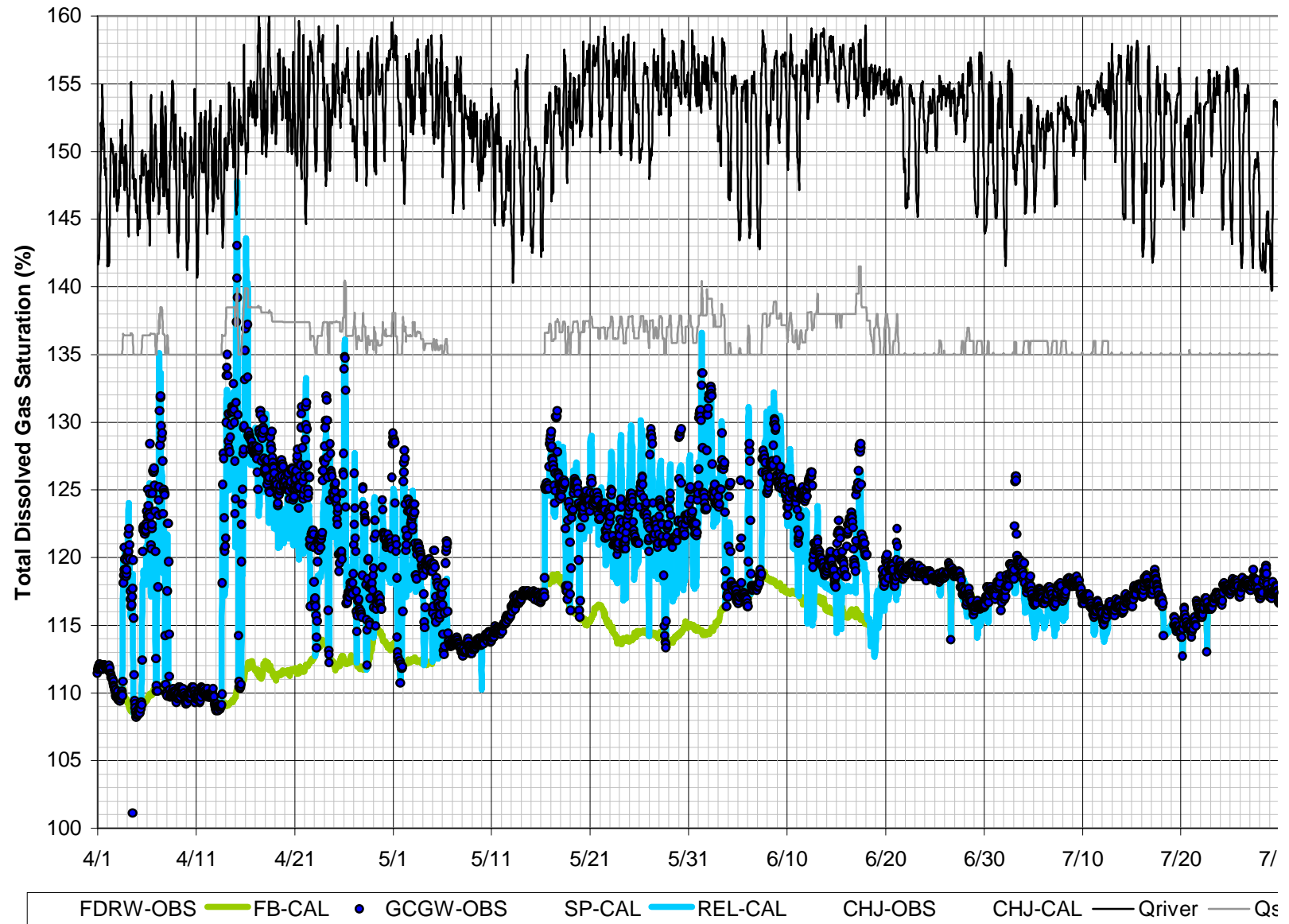
Time

TDG Saturation (Calculated and Observed)

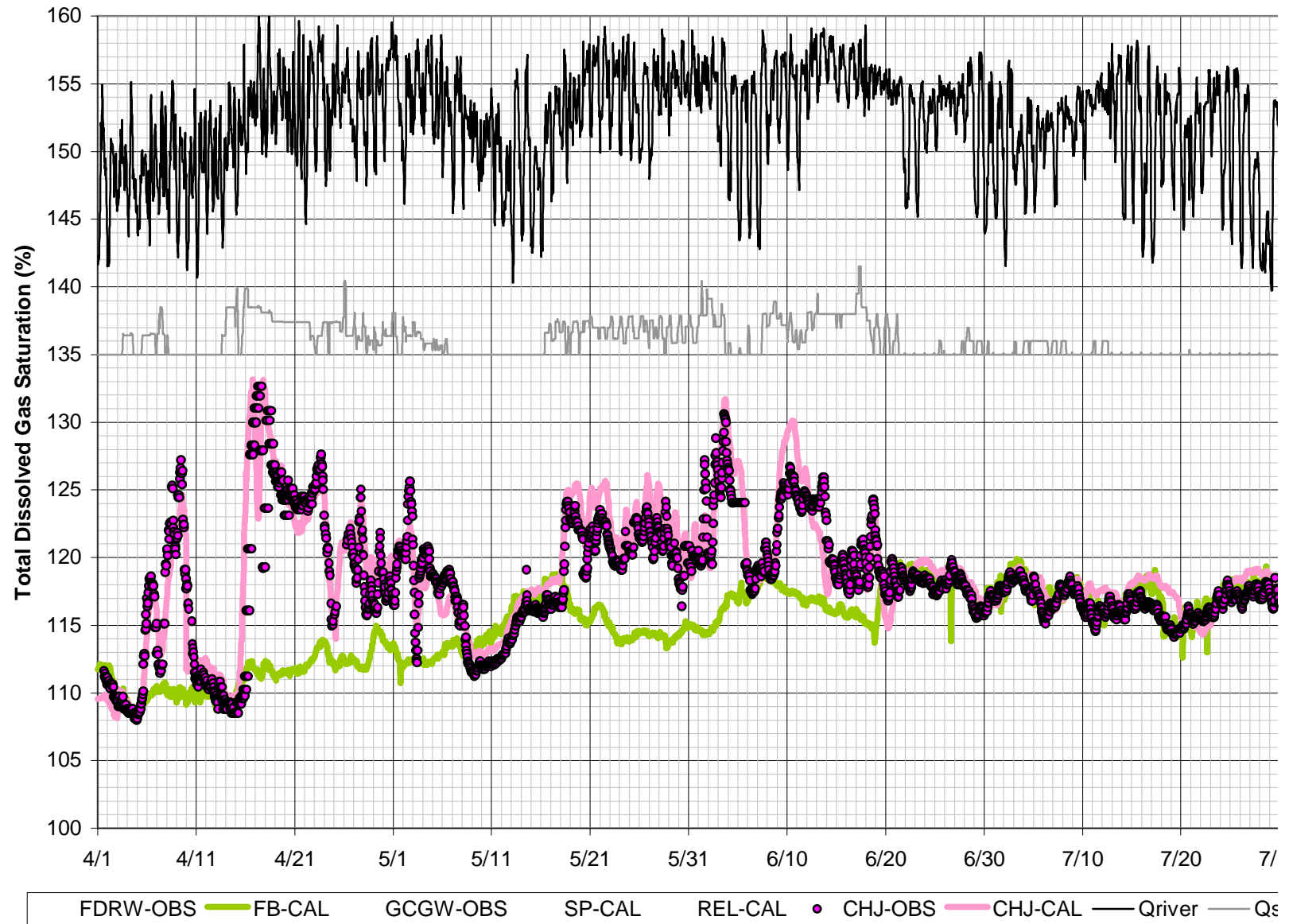




# Grand Coulee Dam



# Grand Coulee Dam



# Chief Joseph Dam

